Land & Climate Review

The scientific case against burning forest biomass for energy

Briefing Note

March 2023

Bioenergy in the EU's energy mix.

Biomass is derived from organic material such as trees, plants, and agricultural waste. It can be used for heating, electricity generation or as liquid fuel for transport. Bioenergy was treated as renewable fuel in the Renewable Energy Directive 2009/28/EC and has since grown into a multi-billion-euro industry. Today, biomass provides around 60% of the EU's total renewable energy – with around 75% of this going on domestic heating and cooling[1]. With the departure of the UK from the EU, the share of biomass in the EU's generation of electricity fell to around 7% of EU electricity generation. The remaining 10-15% of bioenergy is used in transport. As the EU Joint Research Centre notes:

> Wood is the most important single source of energy from renewables in many Member States. Latvia (29%), Finland (24%), Sweden (20%), Lithuania (17%) and Denmark (15%) had the largest share of wood and wood products in gross inland consumption of energy (Eurostat 2018). A large proportion of solid biomass is used directly by households and other final consumers (industries, services, agriculture/forestry). The use of fuelwood in households is particularly important in France, Italy, Germany, Romania and Poland[2].

In 2022, the consultancy Trinomics estimated that EU member states were spending over €7 billion per year on solid biomass for electricity generation and combined heat and power. This represented a 27% increase since 2015. These subsidies (for the burning of biomass in industrial-scale facilities) are permitted because bioenergy is considered a renewable energy source under the Renewable Energy Directive and – therefore – counts towards the EU's increasingly ambition renewable energy targets. You can see a map of all the bioenergy plants over 20MW in the EU+UK here, compiled by the Environmental Paper Network. And you can see a map of global wood pellets imports and exports here.

The Renewable Energy Directive (REDIII)

EU co-legislators are currently finalising the recast EU Renewable Energy Directive (2018/2001) in light of higher targets for renewable energy sources (RES) called for under REPowerEU, which calls for RES to meet at least 45% of total EU final energy demand by 2030. While adopting this target, in September 2022, the European Parliament also voted to end the practice of subsidising the burning of 'primary woody biomass' for renewable energy in the EU and seek to 'cap and phase down' the amount of wood burned for energy between now and 2030, albeit with some significant derogations. Several member states, under the Swedish Presidency of the Council, have strongly objected to these proposals. The final trilogue is set for 29th March 2023.

Why do scientists oppose the burning of most bioenergy?

As noted, the vast amount of the bioenergy used in the EU is solid (woody) biomass from forests. While data is incomplete, in 2021, the EU's Joint Research Centre estimated that around 37% of the wood burned for energy in the EU is primary wood (a combination of stemwood/tree trunks and other woody components like branches and treetops)[3]. That is to say, it is not coming from 'waste wood' or so-called 'slash'.

---

[1] European Commission, Joint Research Centre, Brief on biomass for energy in the European Union, Publications Office, 2019, https://data.europa.eu/doi/10.2760/546943

[2] Ibid. p.3

[3] JRC 2021 p.41

Most climate scientists and environmentalists oppose the burning of *most* wood for energy for two reasons. The first is that wood – like all organic matter – has a high carbon content but is less energy dense than the fossil fuels for which it is often substituted. This means that, per KWh of energy generated, wood emits around 18% more CO2 even than the most common forms of coal – a figure confirmed by the IPCC's 2006 inventory of greenhouse gases[4]. In this sense, coal is simply more efficient as an energy carrier than wood – both in terms of power and in terms of emissions. There is a reason why the Industrial Revolution was underpinned by a widescale shift from wood to coal.

The second reason that most scientists oppose burning wood is that wood is taken from forests and forests are the world's largest carbon sink, removing and storing many million tonnes of carbon from the atmosphere each year. Anything that reduces the rate at which forests remove carbon from the atmosphere has the same net effect as an emission of CO2 *into* the atmosphere. Harvesting wood for bioenergy not only releases the *stock* of carbon previously stored in soil and plant biomass into the atmosphere but also – generally – reduces the annual *flow* of carbon into the forest per year.
It is true to say that managed plantations and agroforestry (which combines tree growth with croplands or pastures) can often achieve initially higher growth rates per hectare and – therefore – higher rates of CO2 sequestration per hectare than a natural forest, as a comprehensive 2018 study of over 335 scientific peer-reviewed manuscripts and published reports found . But, as the authors of that study acknowledged, it is important to take into account long term carbon storage – as well as the energy inputs which go into the planting and maintenance of managed plantations and the effects on biodiversity when considering global-scale afforestation and reforestation strategies for the long term.

And as Professor Simon Lewis et al highlight in a 2018 paper for leading journal *Nature*[5]:

> One of the major reasons plantations are not ideal for carbon storage is that regular harvest and clearing tends to release carbon dioxide every 10 to 20 years. However, natural forests, when left undisturbed, will continue to store the carbon for decades. A conservationist can understand why a monoculture of eucalyptus trees harvested regularly may not qualify as restoration, but the public can be misled by policymakers employing broad definitions of forest restoration.

Indeed, Lewis's research points to a much higher carbon sequestration potential for natural forests, which contain a mix of species and are not grown either for energy crops or for exploitation by the timber, paper and packaging trade.

> In short, if the entire 350 million hectares [based on the commitments mentioned above under the Bonn Challenge] is given over to natural forests, they would store an additional 42 petagrams of carbon by 2100. Giving the same area exclusively to plantations would sequester just 1 petagrams of carbon or, if used only for agroforestry, 7 petagrams of carbon.

These findings can be set beside important, 2014, findings from the US Geological Survey's Nathan Stephenson's et al, in a study which examined the rates of carbon accumulation over time of over 400

[4] Intergovernmental Panel on Climate Change (2006). "Table 2," Guidelines for National Greenhouse Gas Inventories, Vol. 2 (Energy), pp 2.16-2.17. Available online at: https://www.ipcc.ch/report/2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/

[5] Lewis et al "Restoring natural forests is the best way to remove atmospheric carbon" Nature 568, 25-28 (2019): doi:10.1038/d41586-019-01026-8

different species of single tree. Again, while it is often argued that young trees will outstrip older, larger trees in terms of growth rate and sequestration productivity, Stephenson argues that:

> Large, old trees do not act simply as senescent carbon reservoirs but actively fix large amounts of carbon compared to smaller trees; at the extreme, a single big tree can add the same amount of carbon to the forest within a year as is contained in an entire mid-sized tree…
> The apparent paradoxes of individual tree growth increasing with tree size despite declining leaf-level and stand-level productivity can be explained, respectively, by increases in a tree's total leaf area that outpace declines in productivity per unit of leaf area and, among other factors, age-related reductions in population density.

In other words, older trees have more leaves and so are able to sequester more carbon, even at a lower rate per leaf than younger ones.

Is burning wood for energy worse than burning coal?

Three of the most widely cited, peer-reviewed, papers on the impact of burning wood on atmospheric carbon are:

- Michael T. Ter-Mikaelian, Stephen J. Colombo, Jiaxin Chen, 'The Burning Question: Does Forest Bioenergy Reduce Carbon Emissions? A Review of Common Misconceptions about Forest Carbon Accounting', Journal of Forestry, Volume 113, Issue 1, January 2015, Pages 57–68, https://doi.org/10.5849/jof.14-016
- John D Sterman et al 2018 Environ. Res. Lett. 13 015007
- Norton, M, Baldi, A, Buda, V, et al. Serious mismatches continue between science and policy in forest bioenergy. GCB Bioenergy. 2019; 11: 1256– 1263.

All are clear that the simple assumptions that the re-growth of trees can compensate for the immediate release of additional CO2 into the atmosphere are flawed.
In the Ter-Mikaelian et al paper, several scenarios are examined in which the harvesting and burning of live trees substitutes for coal. As the authors say: 'These studies consistently show that harvesting live trees to produce bioenergy initially increases greenhouse gas emissions which may take decades to centuries to offset [even against coal]'. (p.60).

John Sterman and Juliette Rooney-Varga's paper, meanwhile, yields similar findings:

> 'Because combustion and processing efficiencies for wood are less than coal, the immediate impact of substituting wood for coal is an increase in atmospheric CO2 relative to coal. The payback time for this carbon debt ranges from 44-104 years after clear-cut.'

A similar point is made by Norton et al, in a paper published by scientists from the European Academies Science Advisory Council in 2019:

> Current policies are failing to recognize that removing forest carbon stocks for bioenergy leads to an initial increase in emissions. Moreover, the periods during which atmospheric CO2 levels are raised before forest regrowth can reabsorb the excess emissions are incompatible with the urgency of reducing emissions to comply with the objectives enshrined in the Paris Agreement.

What if overall forest growth 'outstrips' removals?

The argument is often made that if the annual growth of a forest exceeds total removals, this means that bioenergy from forests is *carbon neutral* (the 'sustainable forest management' argument). This is not correct, and the fallacy is subject to rebuttals in a large amount of academic literature, including in several of the detailed studies produced for the European Commission. It is a good example of the terms 'sustainable' and/or 'renewable' being misunderstood to be the same as carbon neutral. Ter-Mikaelian explains:

> 'Stating that sustained yield management is carbon neural is incorrect because it fails to account for the case involving no harvest for bioenergy' (p.62).

What is essentially happening is that the *undisturbed part of a forest is being used to offset removals from the stands subject to logging*. Mary Booth and Ben Mitchell provide a visual explanation of this in their 2020 report *Paper Tiger* (p.9).

Removing wood from forests always reduces the rate at which they can sequester carbon and that affects the carbon sink when compared to a situation in which wood is not removed.

These papers, and papers like them, led the Joint Research Centre to conclude, in 2021, in a 165 page report into 'The Use of Woody Biomass for Energy Production in the EU', that all types of wood removed from forests for bioenergy, but one, increased emissions by at least two decades while harming biodiversity. Only the removal of slash (twigs and other very small branches) could provide climate and biodiversity benefits within 1-2 decades (p.9).[6] Needless to say, slash is a tiny fraction of the wood used for bioenergy in Europe today and could never be a large proportion.

The EU's forest carbon sink is already declining

Even before the Renewable Energy Directive of 2009 provided incentives for bioenergy, the EU was felling nearly two thirds of the net annual growth of its forests every year. Since 2016, Fine-scale satellite data have shown an increase in the harvested forest area of 49 per cent and an increase in biomass loss of 69 per cent across Europe for the period of 2016–18 relative to 2011–15. The lead author on that study was Guido Ceccherini, of the EU's Joint Research Centre. The study (published in the journal *Nature*) stated that:

> The increase in the rate of forest harvest is the result of the recent expansion of wood markets, as suggested by econometric indicators on forestry, wood-based bioenergy and international trade. If such a high rate of forest harvest continues, the post-2020 EU vision of forest-based climate mitigation may be hampered, and the additional carbon losses from forests would require extra emission reductions in other sectors in order to reach climate neutrality by 2050.

[6] Camia A., Giuntoli, J., Jonsson, R., Robert, N., Cazzaniga, N.E., Jasinevičius, G., Avitabile, V., Grassi, G., Barredo, J.I., Mubareka, S., The use of woody biomass for energy purposes in the EU, EUR 30548 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-27867-2, doi:10.2760/831621, JRC122719

You can read a submission from the Forest Defenders Alliance on the initial proposals in the EU Land Use and Land Use Change Directive – and why they are inadequate for the protection of forests here. The authors referred to the problems involved in the setting of forest reference levels at a higher level than current harvesting:

> Under the current LULUCF Regulation, Member States must ensure their forest carbon sink does not fall below a projected sink based on continuation of management practices in the 2000 – 2009 period. This always would have been inadequate to meet climate goals, but it was truly shocking to see the process for setting the Forest Reference Levels (FRLs) play out. In the end, half of member states (MS) projected that the way they plan to manage their forests will reduce their forest sink relative to the 2016-2018 average, and the majority of these plan to reduce their sink by 20% or more. Collectively, the EU's 2021-2026 forest sink is projected to decline by 11% compared to the average forest sink from 2016 to 2018.

Scientist interventions against biomass

Professional research scientists and independent research bodies have been publishing and speaking out against classifying wood burning as renewable energy for as long as there has been legislation in this area.

In 2009, an article in the journal *Science* by **Timothy Searchinger** et al, identified a 'major, but fixable, carbon accounting flaw in assessing bioenergy' in the Kyoto Protocol and national climate legislation. 'This accounting erroneously treats all bioenergy as carbon neutral, regardless of the source of the biomass, which may cause large differences in net emissions. *For example, the clearing of long-established forests to burn wood or to grow energy crops is counted as a 100% reduction in energy emissions, despite its causing large releases of carbon.'*

In 2011, former IPCC lead author, **Professor Bill Moomaw,** wrote a warning letter to policymakers, "The Myth of Carbon Neutrality of Biomass".

In January 2018, as the EU was reassessing the renewable energy directive which had led to a huge increase in the amount of wood being burned for energy, a group of 77**2 scientists** wrote a letter to MEPs, as the European Parliament scrutinised the sustainability criteria for bioenergy as part of the EU's recast Renewable Energy Directive. The list was headed by Professor John Beddington, former Chief Scientist to the UK government. When the Renewable Energy Directive passed the European Parliament in 2018, Tim Searchinger and a number of other leading scientists published a critical commentary in *Nature Communications.* They concluded that:

> "Overall, replacing fossil fuels with wood will likely result in 2-3x more carbon in the atmosphere in 2050 per gigajoule of final energy."

Dr Mary Booth's paper in *Environmental Research Letters* ("Not carbon neutral: Assessing the net emissions impact of residues burned for bioenergy") can be accessed here. Details of the case that Booth and others brought against the EU's Renewable Energy Directive in 2020 can be found here. The accompanying report, "Paper Tiger", can be read here.

In September 2019, the **European Academies Science Advisory Council (EASAC)**, which includes the national science academies of 18 EU countries, published a landmark paper (referred to above)

arguing that 'Serious mismatches continue between science and policy in forest bioenergy'. This was on top of a 2018 commentary on "Forest Bioenergy and Carbon Neutrality". Ahead of the COP25 meeting in Madrid in December 2019, EASAC scientists issued a further statement to policymakers: 'We have repeatedly pointed out that in many cases the large-scale substitution of coal by forest biomass will accelerate climate warming.' In May 2020, EASAC issued a further statement in response to complaints by a body representing the bioenergy industry. And in August 2020, EASAC issued a recommendation to the European Commission that biomass burning be included in the EU ETS (Emissions Trading System). In 2021 EASAC published a further letter defending the claims made in its 2019 paper.
In 2018, **Forest Research**, the UK's principal organization for forestry and tree related research published a supplementary analysis based on research complied for the European Commission itself: "Carbon impacts of biomass consumed in the EU". The report modelled several scenarios for the EU. The authors stated that:

> 'Unless appropriate policy measures are taken to support sustainable bioenergy supply (in terms of impacts on GHG emissions), particularly in the case of forest bioenergy supply, a significant increase in bioenergy use in the EU is likely to lead to a net **increase**, rather than decrease, in GHG emissions being contributed from bioenergy sources.'

The lead author of that report later gave an interview complaining of how his findings had been presented by the European Commission – and went on to publish a clarification report. You can read a *Land and Climate Review* commentary on that report here.

In 2017, **Chatham House**, in the UK, published a series research papers on *Woody Biomass for Power and Heat: Impacts on the Global Climate.* The reports highlighted the dangers of expanding wood burning in Europe and pointed out the flaws in assuming that forest bioenergy is carbon neutral: 'Replacing large mature trees, with plentiful leaf cover absorbing large volumes of carbon dioxide, with small young ones mean that the rate of carbon uptake will be far lower for years'.

In September 2021, **Chatham House and Woodwell Centre** researchers provided one of the most detailed studies linking CO2 emissions to specific wood pellets milled in US (all of which were exported to the UK and EU) – estimating that woody biomass sourced in the US and used for energy generation within the EU27 will be responsible for 8 million–10 million tonnes of associated CO_2 emissions in 2025. This will be higher in 2030 if further coal-to-biomass conversions go ahead.

There have been three significant interventions from independent scientists into the debate over bioenergy and forestry since Bill Moomaw's letter to EU policymakers in 2011. In 2018, **772 scientists** including former Vice-Chair of the IPCC (who is now running to be chair) Jean-Pascal van Ypersele wrote to the European Commission urging them to review the Renewable Energy Directive, arguing that

> "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."[7]

[7] Read the full letter here. 11 Jan 2018

In 2021, with the Renewable Energy Directive back under consideration as part of the Fit For 55 package, **500 scientists** again wrote to world leaders, EU member states and the European Commission calling for an end to subsidies for wood burning and highlighting that 'there is good evidence that increased bioenergy in Europe has already led to greatly increased forest harvests [in the EU]'. Van Ypersele also published an article underlining that "trees are worth much more to humanity alive than dead". In 2022, **38 of these scientists** followed up with recommendations to EU policymakers to amend the provisions of the Fit for 55 package, under which Commission modelling indicated that 'energy crops by 2050 will occupy 22 million hectares in Europe, roughly a fifth of Europe's cropland'.

Ahead of the UN COP15 conference on biodiversity in December 2022, **650 scientists** wrote to world leaders, urging them 'to stop burning trees to make energy because it destroys valuable habitats for wildlife'.

Also in December 2022, a group of academics at the Oeko-Institut in Berlin and the Finnish Environmental Institute published work examining the carbon storage of wood, based on studies of forests all over Europe, providing a fine-grained estimate of the amount of carbon being transferred from the forest to the atmosphere when wood from specific forests is burned. With specific regard to the methodology used by the REDIII, the authors findings served to confirm the fears of many scientists working in the field:

> The annexe to the Renewable Energy Directive II (page 174) states that if stemwood (i.e. whole trees) is used for energy, an emissions saving of over 80% over fossil equivalents can be assumed. If we assume a carbon storage loss of zero, these numbers will yield an emissions savings over fossil fuels.
>
> But if we plug in a carbon storage loss of 0.62 tonnes of CO_2 m^{-3}, we find that wood harvesting for energy will actually serve to raise emissions 13% over a fossil fuel equivalent. If we plug in the mean level of carbon storage lost in Germany (of 1.15 tonnes of CO_2 m^{-3}) into the equations, we find that firewood and wood chips, when sourced from primary woody biomass, actually *more than double* the emissions associated with burning them as a substitute for fossil energy (see details in Hennenberg et al. 2022 and Fehrenbach et al. 2022).[8]

In line with these findings, and ahead of a major vote in the European Parliament on the EU's Nature Restoration Law, in January 2023, a group of **557 scientists** led by Anders Sirén of the University of Turku, Finland, and David van der Spoel of Uppsala University, Sweden, wrote to MEPs and the EU member states arguing that 'climate smart forestry is a bluff' – and that protecting natural forests was by far the best way to protect biodiversity and enhance carbon recovery and storage:

> Although carbon uptake is faster in managed forests or timber plantations than in natural forests, even natural forests continue to accumulate carbon. In contrast, managed forests have a much lower carbon stock, because approximately half of the carbon that could be stored in a mature forest, is in the atmosphere instead. All carbon uptake in managed forest is therefore a payback of the historical carbon debt.

NGO investigations and media

[8] Robinson et al 'Why burning primary woody biomass is worse than fossil fuels for climate'- EurActiv 13 December 2022

Almost all international NGOs with a focus on and expertise in forestry oppose large scale bioenergy and the harvesting it encourages in forests all over the world. Over the last five years, there have been numerous in depth investigations exposing the impact of the bioenergy sector on forests.
These have included a major investigation by a team of journalists in 2020 and 2021 which found logging taking place in Estonian forests designated as Natura protected zones. Importantly, the investigation found that '40% of the wood that [major Estonian wood pellet company] Graanul Invest harvests on this land comes from whole trees deemed not straight enough or the right size, for such uses such as furniture or construction. This "low-quality wood", as it is called in the trade, is crushed and turned into wood pellets.' This is precisely the 'low quality' primary woody biomass that the European Parliament is trying to protect.

In 2022, The New York Times published an investigation with pictures and maps showing the extent of logging for bioenergy taking place in some of the oldest growth forests in the EU, in Romania. Again, this was taking place in forests that were supposed to be protected. The investigation tragged the trucks carrying the stemwood to mills that grind them into sawdust and pellets. Some of these wood pellets – which are sold for energy all over Europe, including to Italy and Germany – come from potentially centuries-old trees.

In 2021, an investigation for the British newspaper the *Daily Telegraph* found evidence of wood pellets from 'some of Europe's most important forests, including rare habitats that are supposed to be protected under EU law' being shipped to Drax power plant in the North of England, the largest biomass-burning facility in Europe. This has prompted increased ministerial scrutiny of Drax's plans for large-scale Bioenergy with Carbon Capture and Storage.

In 2022, the BBC Panorama found evidence of Drax's own pellet mills logging cutting down primary forests in the US and Canada. This was detailed in a 30-minute documentary which aired on the BBC on 8th October 2022.

In April 2022, the Forest Defenders Alliance published a major investigation into the wood sourced for bioenergy within the EU. 'Of the 43 facilities the report examined across several EU member states, 21 are power or CHP facilities,16 are pellet plants, 5 produce both power and pellets, and one is a wood chip producer. *Most appear to be using significant amounts of stemwood*, including what appear to be very old trees from natural forests. Several plants built in recent years are already using large logs'.

The report used images from Google Earth and other satellite-based imaging, as well as on-the-ground photography, to show the significant numbers of whole logs piled up outside facilities, in many cased owned by companies which claimed not to be using whole logs:

> We viewed company websites and other materials for statements about the types of wood the industry used. We found 11 companies (about 25% of the total) that made statements concerning the type of wood used that did not align with what can be seen in the images[9].

NGO calls to end subsidies for biomass burning

[9] Chamberlain, Booth and Grommerch, *Future on Fire: How the EU Burns Trees in the Name of Renewable Energy,* April 2022, Page 9

In February 2023, 24 EU NGOs signed a joint-position calling for the EU to end subsidies for biomass burning under the Renewable Energy Directive and this was followed by 115 NGOs from America and Canada. Nearly a quarter of a million people and NGOs have signed a WeMove petition calling on the EU to:

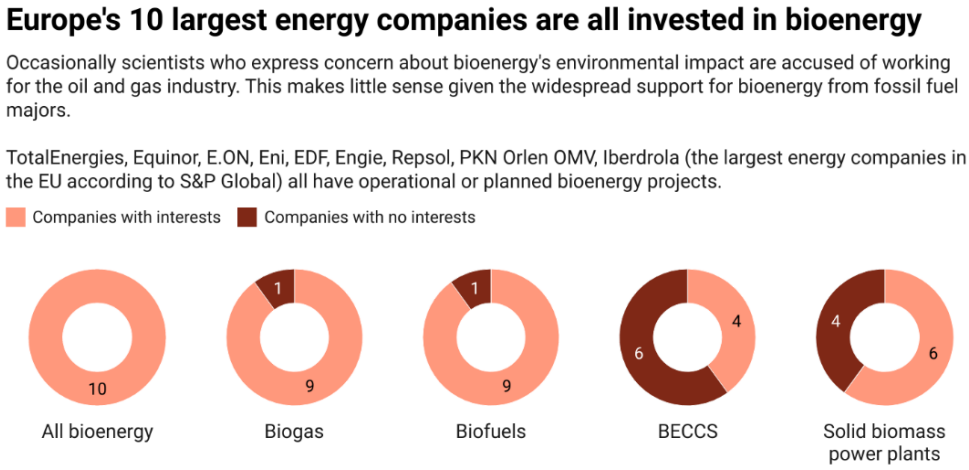
We therefore call on EU policymakers and EU Member States to:

- End subsidies and other incentives for burning forest wood and redirect this critical support to energy efficiency and true low-emissions renewable energy sources
- Exclude energy generated from burning forest wood from counting toward renewable energy targets
- Prioritise forest protection and restoration and ensure that all EU policies safeguard our health, the climate and biodiversity

In 2022, public health organisations Klimawandel Gesundheit (KLUG), Health and Environment Alliance (HEAL), European Public Health Alliance (EPHA), *Deutsche Gesellschaft fuer Public Health* (DGPH) and ClientEarth sent a letter to MEPs pointing out the health and climate impacts of burning biomass. You can also read a March 2023 'Mythbuster' on forest biomass from NGO WWF, here.

Fossil fuel companies backing bioenergy

Bioenergy lobbyists occasionally allege that critical campaigns and research around the climatic and environmental impacts of bioenergy are not led by scientists and NGOs, but instead are funded by the fossil fuel sector. While this was a more nuanced conversation 20 years ago, today it couldn't be further from the truth. As the NGO Transport & Environment have discussed, the Renewable Energy Directive enabled oil and gas majors to shift to biofuels and biogas. This trend has continued, with power companies increasingly planning biomass power facilities (some with CCS, known as 'BECCS'), sometimes touted as a means of avoiding stranded assets[10].



Click here to view interactive chart, or here to view the data in a table.

Today, Europe's 10 largest energy companies are all invested in bioenergy, and promote positive messaging about its climatic and environmental impacts in official media. E.ON, EDF, Engie and Iberdrola all operate numerous solid biomass power plants. This trend is replicated outside Europe, but to a lesser extent in areas without EU policy: 25 out of the top 30 non-EU energy companies have bioenergy investments, but only four have operational solid woody biomass power projects, after a run of failures in the 2010s[11].

A 2020 study interviewing the 24 most highly-polluting companies in Sweden and Finland found that high-emission energy companies and forestry companies held very different attitudes towards bioenergy with CCS. The interviews revealed that energy companies were four times more likely to invest in Bioenergy with Carbon Capture and Storage, despite the forestry companies having conducted more studies on the topic. This is because companies plan "substitution of fossil fuels with biomass for energy", with policy – specifically EU policy – being the "most significant" determiner of whether they enact these plans.

This represents a serious risk.

[10] E.g. see Xing et al., 'Spatially explicit analysis identifies significant potential for bioenergy with carbon capture and storage in China', *Nature Communications* 12:3159. https://doi.org/10.1038/s41467-021-23282-x

[11] See full spreadsheet here. 'Top 40' rankings are based on S&P Global's 2022 rankings.

As modelled in a 2022 study published in *GCB Bioenergy*, Europe relying on biomass power to meet emissions targets could result in **more than 1300MtCO2-e emissions going missing from accounts between 2020 and 2050**, with Europe losing $5 billion to America through wood pellet imports, and European bioenergy companies avoiding paying $14 billion in emissions penalties. The research also found that a bioenergy-reliant Europe "could have significant impacts on forest stocks around the world". Modelled impacts included diminished European biodiversity, increased European vulnerability to climate impacts, and reduced carbon sinks in the USA to the extent that "the United States may need to rely upon other, potentially more costly sources of mitigation to meet domestic climate policy goals."

Edward Robinson
Land and Climate Review
March 2023