Cerulogy

What does it mean to be a renewable electron?

Regulatory options to define the renewability of electricity used to produce renewable fuels of non-biological origin

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1. Introduction

In the European Union, renewable energy policy is guided by the Renewable Energy Directive, which sets targets for both overall renewable energy use and for the use of renewable energy in transport. In transport, the main route to supply renewable energy in the past decade has been the use of liquid biofuels blended into the petrol and diesel supply, complemented by some use of renewable electricity in electric drive vehicles. Moving into the 2020s, expectations are high for the development of a third route to supply renewable energy for transport, whereby renewable electricity will be used to synthesise 'renewable fuels of non-biological origin', also sometimes referred to as 'RFONBOs', 'RFNBOs', 'ReFuNoBiOs, 'power-to-liquids', 'electrofuels' and 'e-fuels'. In this paper, we will use the term RFONBO. Strictly speaking, the RFONBO category is not limited to fuels from renewable electricity, but we do not consider other RFONBO technologies in this paper.

RFONBOs for transport can include hydrogen produced by electrolysis and supplied to fuel cell electric drive vehicles, but with additional chemical synthesis steps synthetic gaseous and liquid fuels (such as renewable methane, methanol, diesel and/or jet fuel) can also be produced. When compared to potentially low carbon biofuels, RFONBOs are expected to have several appealing sustainability characteristics including lower land use and water use requirements, and therefore some commentators and analysts see RFONBOs as a key technology to decarbonise transport energy uses that cannot be readily electrified.

While RFONBOs have appealing sustainability characteristics compared to biofuels, it is important to understand that RFONBOs suffer from inherent inefficiencies compared to the direct use of electricity in electric vehicles, which create sustainability risks particular to the RFONBO industry. In the case of electric vehicles, some climate benefit can generally be delivered even when current grid electricity is used due to increased drive efficiency compared to the combustion engine, along with significant co-benefits in terms of reduced air pollution. Using electricity for transport as liquid fuel[1] via RFONBO production is about five times less efficient than supplying it directly for battery electric vehicles due to energy losses in RFONBO production coupled to the relative inefficiency of the combustion engine. This means that it is vital that electricity for RFONBOs has an extremely low GHG intensity if any CO_2 emissions reductions are to be delivered. As we will discuss in more detail below, the use of current EU grid average electricity to produce liquid RFONBOs would result in emissions three times higher than a fossil fuel comparator.

There is broad agreement that RFONBOs from renewable electricity have the potential to be an important part of the transport energy mix, subject to deploying the technology at commercial scale and getting access to electricity at a low enough cost to make the process economically viable. There is more debate, however, about when it is appropriate to treat the input electricity as renewable.

For a simple case, imagine a windfarm on some remote island far from Europe, connected directly to a RFONBO production facility with no connection to any grid electricity, with the produced fuel being shipped to the EU to be blended into the fuel supply. In such a situation, there is a clear argument that the fuel should be treated as renewable, because the electricity

1 The energy losses could be smaller for renewable methane, DME or methanol, but the basic hierarchy of efficiencies is the same.

consumed is being generated specifically to supply the RFONBO facility and the electrons supplied are coming directly from a windfarm.

Now consider a similar case, but instead of located on a remote island the windfarm and RFONBO facility are situated within the EU and are connected to the electricity grid. Adding a grid connection has several advantages. For one thing, if the maximum electricity generation capacity of the windfarm is larger than the consumption capacity of the RFONBO facility, then excess electricity can be exported to the grid instead of being wasted. Similarly, if the RFONBO facility has downtime then the generated electricity could be exported instead of used locally. If electricity is only ever exported and never imported from the grid to power the RFONBO facility, there still seems to be a strong case that the fuel produced is entirely renewable. The picture becomes more complicated if electricity is allowed to flow in the other direction. If there is no wind and therefore no power being generated locally, could there be circumstances in which fuel produced using electricity imported from the grid could be treated as renewable? If some import of electricity from the grid were to be permitted for a RFONBO facility that is also directly connected to a windfarm, this raises the question of whether and when it could be acceptable to treat fuel as renewable if produced only from grid energy with no direct connection to a renewable power facility? With the power generation occurring within the EU, questions also arise about the relationship to renewable energy policy. If the power is being used to produce a renewable liquid or gaseous fuel that will be counted towards transport targets in the RED, is it acceptable to also count that power generation as renewable towards targets for renewables in heat and power?

There is much to recommend enabling a flexible system whereby renewable power generation and RFONBO production could be geographically separated. One of the reasons that electricity is such a useful form of energy is the ease with which it can be transmitted over large distances. Costs could be reduced if renewable energy facilities can be built where the renewable energy potential is greatest and RFONBO plants can be built near to the relevant fuel markets. On the flipside, however, without a direct link between the renewable electricity facility and the production plant, clear rules would be needed to establish when fuel production should be considered renewable, in order to ensure an environmental benefit from using the fuel. As with any chemical process, synthesising fuel from electricity involves energy losses in conversion, and in the near to medium term one might expect about 50% of the energy from input electricity to be turned into energy in fuel. This energy loss in conversion means that it is extremely important that only very low carbon electricity is used to produce RFONBOs as the carbon intensity of the electricity is effectively doubled into the carbon intensity of the fuel. If even a modest percentage of the electricity used is from fossil sources, the resulting carbon intensity could be higher than the fossil alternative. This is illustrated in Figure 1, taken from (Malins, 2017), which shows that for a plant with a 40% energy conversion efficiency to fuel even using 56% renewable electricity for fuel synthesis would fail to deliver a climate benefit[2].

2 (Malins, 2017) presents a case for RED implementation under which we might expect only 56% of *additional* electricity for RFONBO production to be renewable, even with the use of additionality criteria, due to counting the electricity *input* towards overall renewables targets instead of the energy *output*.

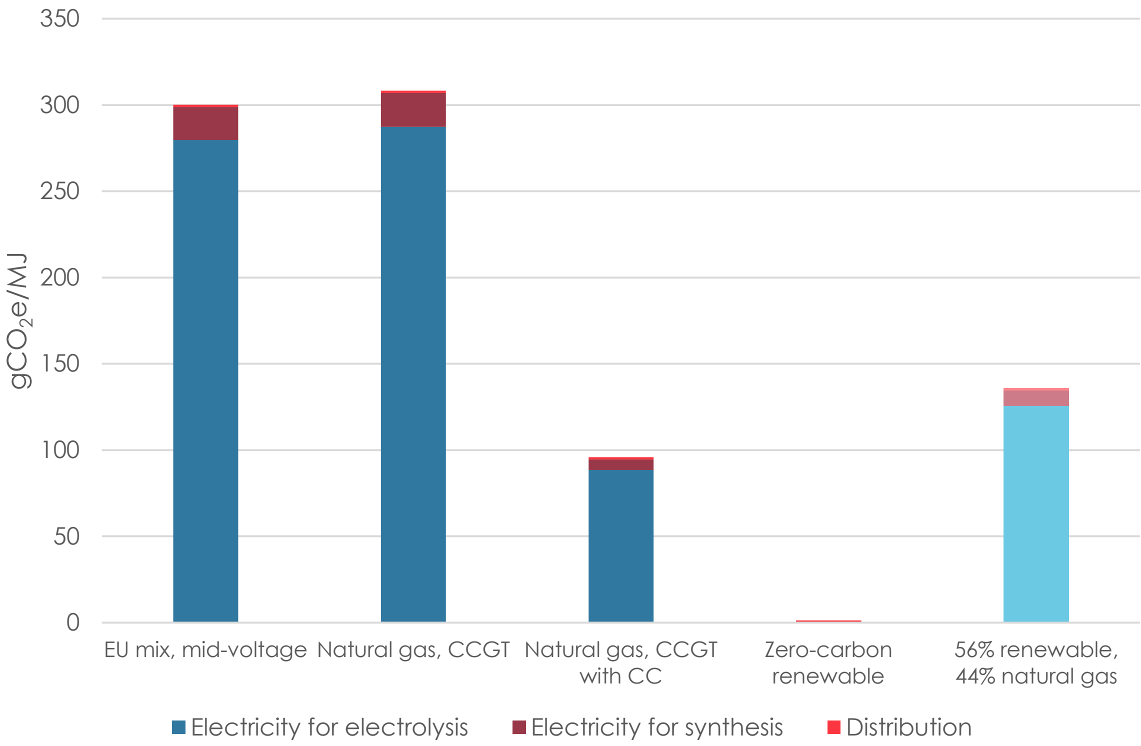

Figure 1. Greenhouse gas intensity of fuel synthesis based on different electricity mixes

Source: Malins (2017)

A recast Renewable Energy Directive (RED II) has recently been adopted by the European Institutions, setting targets and rules for renewable energy use in the EU up to 2030 (EU, 2018). While the new directive addresses the question of RFONBOs, it does not provide a final regulatory resolution on how they will be treated between now and 2030, as it calls for the European Commission to develop two Delegated Acts further specifying the treatment of RFONBOs. These Delegated Acts are to establish a methodology for treating synthesised fuels as fully renewable, and a methodology for assessing the greenhouse gas emission savings delivered by RFONBOs.

In this paper, we review the issues around establishing the renewability of electrofuels, and how that renewability relates to the assessment of GHG savings delivered by use of RFONBOs. We review various options that may be considered for assessing the renewability of electrofuels, and consider the regulatory advantages and drawbacks of implementing each of them.

2. Renewability and additionality

The discussion around the 'renewability' of electricity used for RFONBO production would be relatively simple if renewability was treated solely as a property of a physical flow of electric current, applicable only for flows of electrons driven by a potential difference generated using renewable sources of energy. Under such a direct physical definition of renewability, only projects such as the directly connected RFONBO facilities described in the introduction could be considered renewable. From a policy perspective, however, a physical definition of renewability may be limiting, and may even be counterproductive.

The policy context for identifying energy as renewable or not renewable is the political agreement to seek to limit global heating to less than 2 ° Celsius (and ideally 1.5 ° Celsius). Meeting this target will require an energy transition from the use of carbon-emitting fossil energy to zero or low carbon renewable energy. Government policy in the area of renewable energy and climate change mitigation should therefore have an underlying goal of driving the installation of additional renewable power generation capacity.

In this report, when we discuss renewable electricity for RFONBO production being 'additional', we mean that in a hypothetical counter-factual scenario in which the RFONBO facility did not exist then that amount of renewable electricity would never have been generated or would have been wasted. This stands in contrast to a counter-factual scenario in which the RFONBO facility did not exist and that amount of renewable electricity was still generated and supplied to the grid. (Seebach & Timpe, 2015) argue that 'absolute' additionality can only be delivered in cases where renewable electricity purchased for a given project comes from new renewable power facilities that do not benefit from any other renewable energy support schemes and where the electricity produced is not counted towards any national renewable energy targets or obligations.

For example, if a RFONBO facility was sited next to an existing commercially successful windfarm and drew power directly from it, even though that power might be considered renewable it would not generally be considered additional. Because this additionality assessment rests on a counter-factual, it is difficult to be 100% confident about when power generation is truly additional, but we can make educated assumptions about the circumstances in which renewable electricity use is most likely (or unlikely) to be additional.

When government renewables policy acts directly through requiring or incentivising renewable power generation, it is generally easy to see the link from policy to additional capacity. Provided the policy requires increasing rates of renewable power generation, additional capacity is necessary to meet the targets. This link to additional capacity may not be so obvious, however, when government policy acts by encouraging renewable electricity consumption, for instance by providing incentives to new technologies that can run on renewable power. For example, in the current electricity market businesses and private households may pay a premium to be supplied with electricity described as 'renewable' on a green tariff (based on the use of guarantees of origin), even when that electricity generation was already being generated to meet other government targets and would therefore not be understood as additional. A RFONBO producing facility could sign up for such a green tariff for all the electricity it consumes without causing any additional power to be generated.

This question of additionality in renewable electricity supply is particularly important when policy instruments are introduced aiming to increase both overall renewable energy generation and consumption. For example, Recital 87 of the RED II states that, "Options should be explored to ensure that the new demand for electricity in the transport sector is met with additional generation capacity of energy from renewable sources." If new demand for electricity for transport is *not* matched by additional generation capacity of energy from renewable sources, then one could reasonably argue that transport electrification is in effect increasing demand for fossil power, undermining the potential for climate benefits.

In the context of RFONBOs, the ideas of renewability and additionality become unavoidably intertwined because the climate implications for the system as a whole of taking existing renewable electricity generation and using it to produce liquid fuels are quite different from those of adding additional renewable electricity capacity and using it to produce fuels. As with any chemical process, there are energy losses associated with conversion of electricity into RFONBOs. Based on estimates from the scientific literature of conversion efficiency for electrolysis and fuel synthesis processes, we would expect that in the near term the production of liquid RFONBOs would be only 40-50% efficient (Brynolf, Taljegard, Grahn, & Hansson, 2017; Malins, 2017). Given these conversion losses, twice as much electrical energy is required as an input to RFONBO production than chemical energy is output in the fuel. If there is no requirement for additional renewable electricity to be generated to meet this demand then across the system as a whole total fossil energy consumption could be increased instead of reduced, with an accompanying increase in emissions. This is clearly not the desired outcome from giving public support to alternative fuel use.

2.1. Anticipating capacity responses to new electricity demand (identifying the counter-factual)

Assessing whether given projects or project types are likely to be additional requires making a judgement about what the likely counter-factual scenario would be – and in particular whether the power consumed would have still been generated and supplied to a different consumer in the absence of demand from a RFONBO facility. Identifying the most likely counter-factual in turn requires some understanding of the wider renewable electricity market and policy context.

One important question is what the 'marginal' source of additional power is believed to be. The marginal source of additional power could be any combination of adding new installations, delaying the retirement of older installations and increasing utilisation of operational facilities. There is no simple answer to the question of what constitutes the marginal source of grid electricity. (Timpe et al., 2017) discuss the 'merit order principle' under which it is assumed that power generation options will be utilised in order of cost of additional production. Under this principle, renewable power will always be utilised first because it has the lowest marginal cost for additional use (sunshine is free whereas natural gas is not). The marginal instantaneous source of additional power will therefore tend to be a fossil source, brought into use only when the electricity price rises due to high demand. On this logic, even in a country with a high fraction of renewable electricity generation the marginal source of instantaneous additional capacity is generally a fossil source, and thus if demand is added to the grid from a RFONBO plant one might conclude that this would lead not to additional generation of electricity at grid average GHG intensity, but to additional generation of fossil electricity with a higher GHG intensity than the average.

Following this logic of instantaneous marginal electricity supply, one could conclude that adding demand from RFONBO facilities would be likely to lead to increased utilisation of fossil generation capacity and therefore significant indirect emissions, but the instantaneous marginal supply may not be the same as the longer term marginal supply. If power demand increases by 100 MW for an hour, the grid may rely on burning some extra natural gas, but if power demand increases by 100 MW permanently, the grid might add permanent additional capacity.

If market conditions were such that by 2030 EU targets for renewables were being easily met and the dominant response to any added electricity demand was the installation of new renewable capacity then the market may 'naturally' deliver additional renewable electricity to meet additional demand. This would fall under the category of 'additionality by overshooting demand' identified by (Seebach & Timpe, 2015). The counter-factual would be that this renewable capacity was not added. In this case we would not expect fossil energy use to increase due to RFONBO production. While the EU may be moving in this direction, new fossil power plants continue to be built[3] and most analysts would not yet claim that it can be automatically assumed that any increase in electricity demand would automatically be met through additional renewable capacity. The reality is therefore likely to be more complicated than this.

The flipside of this would be a case in which 2030 EU targets for renewables were being easily met and therefore fossil capacity was being progressively taken offline, but the response to additional demand for RFONBOs was simply to extend the life of fossil power plants that would be retired in the counter-factual. If renewable power production was already in excess of targets, this would be possible without resulting in non-compliance under the RED. This shows that it is possible in principle that *only* fossil energy use would increase in response to electricity demand for RFONBO production.

An alternative case could arise if mandatory targets were driving the level of renewable electricity production. Over the past decade, national policy has been the main driver of the development of renewable electricity generating capacity, through a variety of national targets, incentives and mandates. These policies have been introduced on the understanding that the market alone would not deliver the desired rate of renewables deployment, or in some cases may not deliver renewables deployment at all. In the EU, there is a target for 32% of energy consumed in the to be renewable by 2030. If exactly 32% of EU energy was renewable in the counter-factual scenario and demand for an additional 100 MW of power was introduced, then 32 MW of the additional power would need to be renewable in order to remain compliant with the target. That would allow up to 68 MW of the additional electricity to be fossil based, implying an increase in emissions. This could be true even if the RFONBO facility had a direct relationship with a renewable power facility, as adding renewable electricity capacity in one location would allow a reduction in new capacity installations elsewhere without missing targets (cf. RECS International, 2019; Seebach & Timpe, 2015).

This potential outcome of a net GHG increase could be avoided through regulatory intervention to require additional renewable electricity production to meet the additional electricity demand from RFONBO facilities. Creating a regulatory requirement for additionality is made more challenging because there are no existing systems to clearly demonstrate additionality for EU renewable electricity production. There is a system of guarantees of

3 See for example http://www.airclim.org/acidnews/europe-still-building-new-coal-power-stations

origin (GOs) for renewable energy (discussed further below), but it is designed to show that renewable electricity production is only sold as renewable to a single end consumer, and this does not provide any direct indication of additionality (although the existing GO system does track some relevant information, such as whether a project has received public support). An expanded "GO+" certificating concept has been proposed by (Timpe, Seebach, Bracker, & Kasten, 2017), under which renewable electricity consumed for RFONBOs would be treated as additional only in the case that it is neither incentivised nor counted under other renewables incentives and targets.

The RED II already anticipates the possibility of Member States implementing a restriction on the issue of GOs to projects receiving support from other schemes. Article 19 provides that issue of a guarantee of origin may be withheld if, "Member States decide, for the purposes of accounting for the market value of the guarantee of origin, not to issue such a guarantee of origin to a producer that receives financial support from a support scheme." This would not be a basis for full implementation of the GO+ concept, as it would not preclude projects receiving GOs from being counted towards renewables targets, but could be taken as a starting point for developing a regulatory implementation of the GO+ idea.

As an alternative to ideas like GO+, project level additionality assessment tools for renewable energy projects exist in the context of the UN Clean Development Mechanism (CDM), where they are intended to be used to demonstrate that new renewable energy projects in the developing world would not have been installed without the support of the CDM (UNFCCC CDM EB, 2012). Such an additionality assessment would generally involve showing that an investment in renewable power capacity would not have been financially viable without the RFONBO facility as an electricity offtaker (for instance through an agreed power purchase agreement). The application of such requirements may be possible in the context of RFONBO production, but it should be noted that the effectiveness of the CDM assessment has been challenged by some commentators[4], and that such assessment may be considered burdensome by project developers. The option of an explicit additionality assessment is considered at the end of the section on flexible options to determine renewability, below.

While it would be simple to treat renewable energy production either as entirely policy driven or entirely market driven, the reality is that market and policy drivers are likely to interact in the coming decade, and it could be argued that the market regime for renewable electricity generation in the EU will move gradually from a policy driven paradigm to a market driven paradigm. The impact assessment for RED II found in the central policy scenario that, "Onshore and solar PV become gradually profitable and by 2030 such projects could be financed entirely by the markets" (European Commission, 2016a). The analysis found that 66% of required renewable electricity investments could be financed by the market by 2030 without policy support, although that result is quite sensitive to various assumptions. An effective additionality assessment should therefore consider both policy and market drivers.

2.2. Lifecycle analysis of RFONBOs

Electricity is the main input for RFONBOs, and therefore the assumed GHG intensity of electricity used by RFONBO facilities is highly dependent on the assumed origin of that electricity. The RED

4 For example a recent assessment for the European Commission queried the additionality of some approved CDM renewable energy projects (Cames et al., 2016).

II calls for the European Commission to prepare a delegated act laying out a methodology for assessing the GHG savings delivered by RFONBOs. If the Commission harmonises the basis for assessing the renewability of RFONBOs with the lifecycle analysis framework, then any electricity used in RFONBO production and treated as renewable for the purpose of the renewability assessment would also be allocated a zero or low GHG intensity in the lifecycle analysis methodology (wind, hydro and solar power are all presumed to have zero greenhouse gas intensity within RED, although the picture may be more complicated for geothermal power due to the potential for GHG emissions from geothermal fluids). For the case that only electricity identified as additional renewable electricity was input to the RFONBO facility, this would almost certainly result in a low GHG intensity score for the overall production process. In the case that only some fraction of the electricity input to a facility was considered renewable but not additional, however, the picture could be a little more complicated.

In the case described above where the additional electricity required for RFONBO production was assumed to have a 32% renewable fraction in line with the 2030 EU renewables target, for example, one could argue that the 68% of additional power that was non-renewable should be included in the lifecycle analysis. This could result in a much higher GHG intensity value for the fuel, and could potentially apply in some cases (such as direct connections) under which the regulation would identify the fuel as fully renewable. If this 68% of non-renewable power was anything other than very low carbon, the resulting RFONBO would not meet the required GHG reduction threshold of 70%. In this way, it might be possible to use the LCA methodology to apply an implicit additionality requirement on the sourcing of renewable electricity for RFONBOs. In the rest of the paper, we focus on options to implement a single definition of ‘additional renewable’ electricity, but in principle some of the approaches for additionality discussed below could be applied through the LCA methodology instead of through the renewability assessment.

3. Existing regulatory language in RED II

The Renewable Energy Directive II creates an opportunity for 'renewable fuels of non-biological origin' (RFONBOs), principally fuels produced via electrolysis with renewable electricity, to be counted towards renewable energy targets for transport and to receive support from Member States alongside biofuels. It also establishes some principles based upon which the renewability of an electrofuel can be assessed.

Article 27b paragraph 3 states that,

> *Where electricity is used for the production of … transport fuels of non-biological origin, either directly or for the production of intermediate products, the average share of electricity from renewable sources in the country of production, as measured two years before the year in question, shall be used to determine the share of renewable energy.*

This sets the first option for assessing renewability of electrofuels, which is to assess it directly based on the average renewability of grid electricity in the country of production. The paragraph continues:

> *"However, electricity obtained from direct connection to an installation generating renewable electricity may be fully counted as renewable electricity where it is used for the production of renewable liquid and gaseous transport fuels of non-biological origin, provided that the installation:*
>
> (a) *comes into operation after, or at the same time as, the installation producing the renewable liquid and gaseous transport fuels of non-biological origin; and*
>
> (b) *is not connected to the grid or is connected to the grid but evidence can be provided that the electricity concerned has been supplied without taking electricity from the grid.*

This sets a second option, under which electricity may be treated as entirely renewable if it is supplied directly from a new renewable electricity installation without any electricity being taken from the grid (as for instance in the first example considered in the introduction). The paragraph goes on:

> *Electricity that has been taken from the grid may be counted as fully renewable provided that it is produced exclusively from renewable sources and the renewable properties and other appropriate criteria have been demonstrated, ensuring that the renewable properties of that electricity are claimed only once and only in one end-use sector.*

This third option suggests a more flexible but less clearly defined mechanism to treat electricity as fully renewable. The Commission is tasked to produce a delegated act by 31 December 2021 to establish an implementable methodology for this option.

The intention of the European Institutions in creating this third option is further indication in Recital 90 of the RED II. This states that:

> *To ensure that renewable fuels of non-biological origin contribute to greenhouse gas reduction, the electricity used for the fuel production should be of renewable origin. The Commission should develop, … a reliable Union methodology to be applied where such electricity is taken from the grid. That methodology should ensure that there is a temporal and geographical correlation between the electricity production unit with which the producer has a bilateral renewables power purchase agreement and the fuel production. For example, renewable fuels of non-biological origin cannot be counted as fully renewable if they are produced when the contracted renewable generation unit is not generating electricity. Another example is the case of electricity grid congestion, where fuels can be counted as fully renewable only when both the electricity generation and the fuel production plants are located on the same side in respect of the congestion. Furthermore, there should be an element of additionality, meaning that the fuel producer is adding to the renewable deployment or to the financing of renewable energy.*

This recital explicitly refers to 'power purchase agreements', refers to the possibility of treating grid electricity as renewable when its delivery to other users is restricted by congestion, and clarifies that the generation of renewable power must be temporally consistent with the claim to use renewable power. These are therefore issues that we might expect to be considered in the development of the delegated act by the Commission.

3.1. Contribution of RFONBOs to overall renewable energy targets

The RED II distinguishes in assessing the gross final consumption of energy from renewable sources between consumption of a) renewable electricity, b) renewable heat/cooling and c) renewable transport energy (Article 7 paragraph 1). Biofuels and renewable electricity consumed in the transport sector are to be assessed as part of the third term, renewable transport energy, but RFONBOs from renewable electricity are treated differently:

> *Renewable liquid and gaseous transport fuels of non-biological origin that are produced from renewable electricity shall be considered to be part of the calculation pursuant to point (a) of the first subparagraph of paragraph 1 only when calculating the quantity of electricity produced in a Member State from renewable sources.*

There is a degree of ambiguity (in the author's opinion at least) stemming from this language as to how electricity used to produce RFONBOs should be accounted as regards compliance with overall renewable energy targets. For one, the language of this clause refers to "calculating the quantity of electricity produced from renewable sources" while Paragraph 1 a) refers to "gross final consumption of energy from renewable sources". The ambiguity between consumption and production statistics is heightened by the context – for a RFONBO process with a 50% energy conversion efficiency, the electricity consumed by the RFONBO process is double the energy finally consumed by a transport fuel consumer. The most consistent way to deal with energy supplied in RFONBOs would be to count it by final energy delivered for consumption (so that a litre of biomass derived renewable diesel would count the same as a litre of RFONBO renewable diesel), but if this is the intention of the Directive it is unclear why it was felt necessary to specify that this energy should be counted in the bucket for renewable electricity rather than renewable transport energy.

Should the Commission or any Member State interpret this article as requiring that the renewable electricity input to RFONBO processes be counting towards targets based on energy input rather than energy output, this would effectively double count RFONBOs towards overall targets. In principle, this could lead to a policy-mediated indirect emissions effect, if it resulted in a slight relaxation of other Member State renewable targets, and therefore in allowing reductions in renewable energy supply in other sectors. This issue is explored further in (Malins, 2017; Searle & Christensen, 2018). Ideally, the European Commission will resolve this issue by providing guidance indicating that RFONBOs should be counted towards overall renewables targets by energy content of the fuel, not of the input electricity.

4. "Inflexible" options to determine renewability

4.1. Grid average renewability

The first accounting option provided by the RED II to assess renewability for RFONBOs is to base it on the renewability of average grid electricity (an option also available for assessing the renewable fraction in electricity supplied for use by electric drive vehicles). [5]The Directive requires the average assessment to be based on data for the two years preceding the year of RFONBO supply. A persistent reliance on data from earlier years will tend to understate the actual renewability of grid electricity at the time of RFONBO supply, as in general the renewable content in grid electricity can be expected to increase throughout the period of application of the RED II. This therefore represents a conservative assessment of the renewable fraction.

As of 2017, Eurostat reports that 26% of gross electricity generation in the EU was from non-biomass renewables (Eurostat, 2019). The local rate of renewable electricity generation varies considerably by Member State, however, as see in Figure 2, ranging from 6% for Estonia to 81% for Luxembourg. This strong variation in renewability would give a significant regulatory advantage under the grid average accounting system to RFONBOs produced in countries with a higher renewable share. Assuming that other eligibility conditions could be met, a batch of RFONBO produced from grid electricity in Luxembourg would receive 18 times more support from RED II than a comparable batch produced in Estonia.

The Impact Assessment on the RED II foresaw around 35% non-biomass renewable electricity generation by 2030 (European Commission, 2016b) under a 27% overall renewable energy target – the final agreed renewable energy target is 32%, suggesting that one might expect something like 40% non-biomass renewables in the EU mix in 2030. It is reasonable to expect that some Member States would have a very high non-biomass renewable electricity generation fraction in this timeframe, making those states relatively appealing for RFONBO production.

5 In line with the "non-biological origin" of RFONBOs, the RED II requires that the renewable fraction of electricity generation calculated for this purpose must exclude electricity generated through biomass combustion.

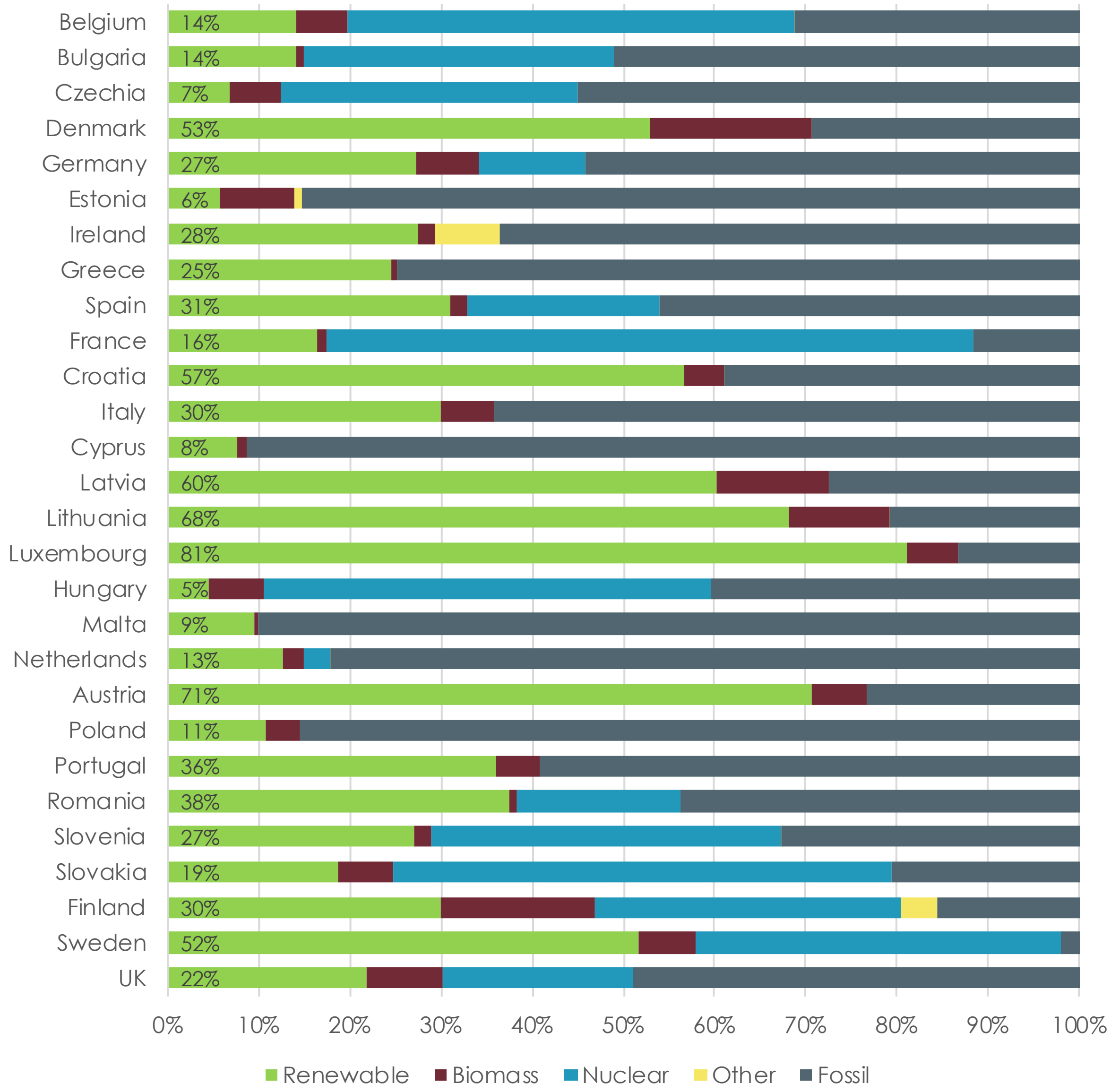

Figure 2. 2017 electricity production in EU Member States

Source: Eurostat

4.1.i) Additionality under the grid average system

One drawback of the grid average approach as a basis to assess the renewability of RFONBOs is that it does not directly guarantee that RFONBO production uses additional renewable capacity. A RFONBO facility using this renewability assessment would be under no obligation to support any additional investment in renewable power capacity. In general, one might expect that Member States with a very high fraction of renewable electricity generation would be likely to be over-compliant with renewable power targets. It may therefore be possible in principle for the power consumption of RFONBO facilities in such a case to be compensated entirely by increased fossil power generation without affecting compliance with EU or national renewables targets. It might also be possible for the power consumption to be compensated entirely by electricity imports from another country with a lower fraction of renewable electricity on the grid. The addition of a single additional RFONBO facility to the grid, even if entirely fossil powered, would not significantly affect overall national average renewability statistics.

The other side of this argument is that presumably in a country where non-biomass renewables are the dominant source of electricity they will have represented the majority of new capacity additions for several years, and it may therefore not be realistic to assume that additional marginal power demand would be met by fossil power. The market in these countries might be expected to respond to additional marginal power demand with additional renewable capacity, even if there is no direct investment by the RFONBO facility in renewable generation. While therefore additionality cannot be guaranteed under the grid average system, a high level of average renewability might be treated as an indicator that additional electricity was likely to be largely renewable.

The lifecycle greenhouse gas emissions intensity for RFONBOs produced from grid electricity will depend strongly on whether the accounting rules require a single average value to be calculated across both the renewable and non-renewable fractions of the fuel, or whether a separate GHG intensity value may be calculated on the renewable part. If a single average value must be used across all produced RFONBO fuel and meet the 70% emissions saving threshold set by the RED II, then RFONBOs would only be eligible for support in countries with a very high fraction of zero (or very low) carbon electricity production. This would apply to countries in which either renewables or a combination of renewables and nuclear power dominated electricity generation (as an indication, we would expect that very low carbon sources would need to be > 90% of the supply).

If on the other hand a separate GHG intensity value was to be calculated for the renewable fraction of produced fuel, then in general we would expect a very low GHG intensity because by definition the input renewable electricity has a low GHG intensity. The carbon intensity on the non-renewable part of the fuel could be large (for instance Figure 2 shows an example of 310 gCO_2e/MJ for a non-renewable fuel of non-biological origin produced using electricity from a natural gas turbine) but this high GHG intensity on the non-renewable part would not be penalised under the RED. Any LCA approach that treated the renewable and non-renewable streams as entirely separate processes would therefore create a risk that the opening of a RFONBO facility could cause a net increase in transport sector emissions when all produced fuel is considered, but still be credited for delivering the renewable fraction as a low carbon RFONBO. Such an LCA approach would also be inconsistent with LCA rules for biofuels, under which co-products of a single physical process are analysed together with emissions allocated between them on an energy basis.

The risk of this outcome is tempered by the fact that it may be difficult to make a project economically viable without receiving incentives for nearly all of the produced fuel (Christensen & Petrenko, 2017). The case in which a significant fraction of produced fuel counts as non-renewable and has a very high associated GHG intensity may therefore be excluded by the economics if not by the regulation.

4.1.ii) Discussion: pros and cons of the grid average approach

The grid average emissions approach is already written into the RED II so needs no additional legislation, and is simple to administrate as the renewability assessment requires only data on recent grid average non-biomass renewability in the country in question and on total fuel produced by the relevant RFONBO facility. It can readily be applied not only for RFONBOs produced in the EU but also in third countries with published grid electricity statistics. On the other hand, this system creates no direct link between RFONBO production and additional renewable electricity capacity, which could result in indirect emissions and could allow RFONBO producers in the Member States with the highest renewable electricity penetration to undercut producers in other Member States who would be required to either have direct connections to renewable electricity generation, or to use a potentially more expensive flexible mechanism to demonstrate wholly renewable status. Under the grid average system deployment of the RFONBO industry would not necessarily support increased renewable power generation and it would therefore be arguable whether deployment truly delivered GHG emission reductions. Given that the grid average approach is explicitly allowed by the RED II, guaranteeing the climate benefits for fuels assessed on this basis would require either regulatory amendment or for the LCA approach to consider the GHG intensity of expected additional electricity generation.

4.2. Direct connection from a renewable electricity generator to a RFONBO facility

The second option for establishing renewability provided by the RED II is to have a direct connection to a renewable energy facility that comes into operation at the same time as or later than the RFONBO facility, and to show that no additional energy was imported from the grid for RFONBO production.

The logic behind this option for demonstrating renewability is fairly clear – if new renewable electricity capacity is built with a connection to a RFONBO facility, and the facility uses only that renewable electricity for fuel production, then the electrons being supplied to the RFONBO facility have a directly renewable source. By requiring that the opening of the renewable electricity capacity is simultaneous with or after the opening of the RFONBO facility, the legislation seeks to add an element of additionality to this assessment option. In particular, this option precludes a RFONBO facility from taking advantage of any pre-existing renewable electricity capacity.

The direct connection approach to demonstrating renewability is simple in conception, but because of this simplicity it may impose additional costs on RFONBO production that would not be imposed under a more flexible scheme. One source of these additional costs is the challenge of pairing up variable renewable power capacity with an electrolyser that is most economically efficient when it is run at full designed capacity for the maximum possible number of hours per year. If the electrolysis capacity of the facility matched the maximum renewable electricity generation potential of the site then whenever renewable electricity generation was below maximum (at night or on cloudy days for solar, on calm days for wind) then some electrolyser capacity would be wasted. Failing to fully utilise the electrolyser capacity would increase the cost burden of capital repayments, and make investment significantly more difficult to justify, given that the economics of RFONBO production are likely to be challenging even in the best case (Christensen & Petrenko, 2017; Malins, 2017; Searle & Christensen, 2018).

The other end of this capacity asymmetry would be to install much more renewable electricity capacity than electrolysis capacity. This way, the ability to run the electrolyser at full capacity could be maximised, although for variable renewables one would still anticipate significant periods when power would not be available, either at night for solar projects or on very calm days for wind. Even when minimising the electrolyser downtime in this way, being unable to run continuously would still increase the burden of capital repayment somewhat. Further, in this case a significant fraction of renewable power would need to be exported from the site during peak production, or else wasted. In one sense, the generation of significant additional renewable power could be considered a bonus from RFONBO development. Investing in so much excess capacity could however also suggest that the renewable electricity generation investment was viable irrespective of the presence of the RFONBO facility. In this case, it again becomes unclear whether the RFONBO facility is consuming renewable electricity that is truly additional or renewable electricity that would otherwise have been supplied to the grid.

4.2.i) Additionality under the direct connection system

The additionality of renewable electricity generated at a directly connected facility will be case dependent, and dependent on other policy considerations. If the consumed electricity is counted toward member state renewables targets, this could allow a reduction in renewable power generation elsewhere in the system. Such double counting should not be allowed in principle for Member State reporting to the EU of overall renewables shares, but might be possible across specific Member State incentives used to implement RED II. A direct connection alone cannot therefore guarantee additional production. If such double counting were precluded, then for a facility with no grid connection one could reasonably assume that the renewable electricity generation plant would not operate without the RFONBO facility as a customer and would therefore be reasonably considered additional.

In the case of a direct connection to a grid-connected facility, additionality is more difficult. If a relatively small RFONBO plant were to be attached to a large grid-connected renewable electricity facility already planned for construction before the RFONBO plant was built[6], it would be unclear at best whether the RFONBO facility had supported any additional capacity, even if electricity was only exported and never imported. Genuinely additional direct connection projects could be identified by applying additionality tests such as imposed in the CDM, but introducing such tests for directly connected projects would likely require legislative changes.

4.3. Additionality assessment similar to that used under the Clean Development Mechanism

As noted above, it is possible to imagine cases in which the rule for direct connections to be treated as renewable would result in the use of non-additional electricity for RFONBO production. This could be tightened up by introducing project-by-project additionality assessments for assessing power generation associated with RFONBO facilities. Such requirements could be based on the existing requirements of the CDM additionality tool (UNFCCC CDM EB, 2012). This approach would be most applicable to the case of a geographically co-located and

6 The Directive requires that the renewable power facility on a direct connection should come into operation at the same time as or after the RFONBO plant, but does not consider which was planned before the other.

connected RFONBO facility and renewable power facility, as it would be challenging to perform such an assessment for facilities connected only across the grid, though in principle one could imagine applying such a test for facilities contracting through a PPA.

Such an additionality assessment would consider whether the renewable power generation associated with a RFONBO facility would be financially viable in the absence of a contract to supply the electricity for RFONBO use. The CDM assessment also considers the possibility of non-cost barriers being overcome by projects, but this is unlikely to be applicable to renewable power generation in the EU. Under such an assessment, projects would be considered additional in the following circumstances:

- The power generation facility is so remote from grid infrastructure that it would not be economically viable to supply to the grid;
- The RFONBO plant is able to commit to a higher purchase price for renewable electricity than could be offered by the relevant electric utility, and thereby enable investment;
- The RFONBO plant is able to provide more price certainty than the relevant electric utility and thereby enable investment.

The main reason to introduce such a requirement would be to avoid the case that part of the electricity from renewable installations that were likely to be built/operative anyway would be diverted away from the grid and into RFONBO production. If implemented effectively, such a requirement should assure that direct connections delivered additionality and reduce the likelihood of indirect emissions compared to the direct connection requirement in the RED II.

As an alternative to a project by project requirement for additionality assessment, it may also be possible for national regulators to identify categories of renewable electricity project that should always be considered additional if supported by a direct connection (or PPA, see below) with a RFONBO facility. For example, if a given Member State identified a general lack of investments in onshore wind projects in a given region, it may be reasonable to assert that new offshore wind projects in that region supported by direct connections/PPAs should be considered additional. This could shift some of the burden of assessment away from RFONBO producers and onto national administrators.

5. Potential "flexible" options to determine renewability

5.1. Guarantees of Origin (GO)

In the European Union, a consumer market for renewable electricity is enabled under the RED by the system of 'Guarantees of Origin'. Under this system, when a unit of renewable electricity is generated a guarantee of origin (GO) may be issued relating to that electricity. The number of guarantees of origin generated will always be equal to or less than the total amount of renewable electricity generated. These guarantees of origin may then be traded on a 'book and claim' basis, and eventually be retired by a final energy consumer. The system of GOs allows final consumers to be confident that each unit of renewable electricity generated can only be sold as renewable once, as each certificate can be retired only once. The trade in GOs from power generator to final consumer allows additional value to be passed back to support renewable electricity production through (or across) the supply chain. GOs have a functioning existing market and are readily available for purchase. GOs are therefore likely to be seen by some stakeholders in the developing RFONBO industry as an appealing basis to make renewability claims for the electricity used in RFONBO production. In this section we discuss the implications of using GOs as a basis for renewability claims without differentiation – in the next section we discuss the possibility of restricting the system to only GOs from new facilities.

The sale price of GOs is not, however, guaranteed and there is no direct link between the market value of GOs and the revenue required to make new investments in renewable power attractive. Indeed, GO prices have generally been very low compared to the wholesale price of electricity and low compared to the additional revenue needed for renewable power to compete with fossil power generation on the market (Timpe et al., 2017). In principle, if the EU renewable electricity market became static with no further investment and no growth from tomorrow onward, the GO market could continue to function allowing end consumers to identify the electricity they purchase as being derived from renewable sources. It is therefore clear that the purchase of GOs in and of itself does not guarantee that additional renewable electricity capacity is brought to market.

One reason for the low value of GOs historically is that the supply of renewable electricity has tended to outstrip consumer demand for green-tariffs, due to the expansion of renewable capacity to meet government targets. With other national support mechanisms (and the value of electricity itself) providing the value signal to drive renewables investment, the pull from consumers has not been a primary driver of the rate of development of renewable capacity.

As an example, if 100 MWH of renewable electricity is generated in a given period but there is consumer demand for only 50 MWh worth of GOs, then basic supply and demand economics suggest that the price of each GO will tend towards zero (or at least will tend down to just cover the administrative cost of running a GO trading system). This is shown in Figure 3, where D_1 and D_2 represent levels of GO demand below the mandated level of renewable electricity generation (Q_1). Only if the demand for GOs exceeds the level of mandated renewable generation does the GO price start to become significant, and would the GO market start to drive increased supply.

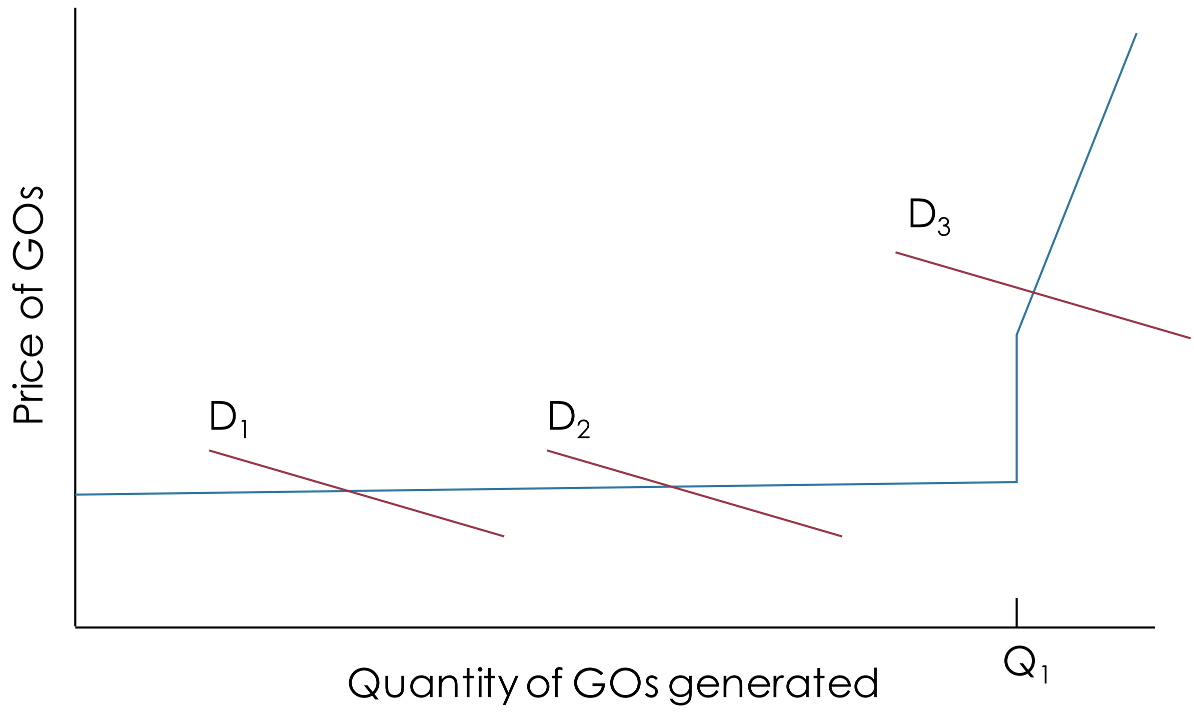

Figure 3. Illustration of relationship between supply and pricing of GOs

Notes: D1, D2, represent demand levels for GOs below the minimum supply of GOs from existing renewable electricity capacity. Only for market equilibria to the right of Q1 will the GO price drive capacity investment (e.g. D3). Source: (Brander, Gillenwater, & Ascui, 2018).

While the RED II provides Member States with some degree of flexibility in administering the GO market, in general we might expect that the GO market in most Member States will continue to be over-supplied for the foreseeable future, with correspondingly low GO prices. As noted above, the RED II does include the option "not to issue such a guarantee of origin to a producer that receives financial support from a support scheme"[7], in which case electricity from renewable capacity receiving other governmental support would no longer be awarded GOs. In this case it would be more likely that demand for GOs would exceed the baseline rate of generation and therefore become a driver of increased renewable electricity supply. Such a system could also, however, deliver significant windfalls to non-additional older projects not receiving government support, such as hydro projects. In such cases, additional analysis would be required to determine whether GOs could be considered as a demonstration of additional supply (for instance considering whether any older renewable capacity was excluded from other government support schemes but still generating GOs).

If the GO market is too weak to drive new capacity investment, then an argument can be

7 RED II Article 19 2).

made that purchasing GOs has no impact on real system-wide CO_2 emissions (Brander et al., 2018). An even stronger argument can be made that by allowing corporate actors to treat some of their associated emissions as zero without delivering any change at the system level, the use of GOs to claim electricity as renewable may actually be counter-productive by providing a distraction from more effective emissions reduction approaches (Nordenstam, Djuric Ilic, & Ödlund, 2018).

One counter argument to concerns about the GO market based on past experience is that while it may have been true in the past that GO purchases have had little impact on renewable capacity, this could change in the future as the drivers of renewable energy capacity shift away from government intervention towards market basics, and if consumer demand for GOs outside of the RFONBO industry increases. This is equivalent to the case in which the supply/demand situation moves past 'Q_1' on the supply demand graph shown in Figure 3. Such a shift to a new market equilibrium is certainly a possibility as the energy transition progresses, but should not be taken for granted. Part of the appeal of GO purchases as a tool for businesses to reduce reportable GHG emissions is the very low cost of the certificates. If the elasticity of GO demand to price is high, then GO prices will not readily shift to a higher level where they would be able to drive investments, and there would never be a one to one correspondence between purchased GOs and additional renewable electricity brought online.

5.1.i) Additionality under the GO system

As discussed above, additionality could not be guaranteed under a GO based system for assessing renewability. Based on our understanding of the existing GO market in the EU, we would generally expect that the purchase of GOs would not drive additional renewable electricity capacity. The level of additional renewable electricity production associated with a RFONBO facility would therefore be determined primarily by market forces in exactly the same way as under the grid average accounting approach (i.e. it would correspond to the renewability of marginal grid electricity supply).

Given that electricity used for RFONBOs under a GO accounting system would not necessarily be additional, there would be a significant risk of indirect emissions under such a system, as there would be no regulatory mechanism to prevent new demand being met by increased fossil power generation.

5.1.ii) Discussion: pros and cons of the GO system

The GO system has appeal because it would rely on an already operational system that is flexible and would impose minimal costs on RFONBO project operators. However, the flipside of these low costs is that requiring GO purchases as a demonstration of renewability would likely do nothing to bring additional renewable electricity capacity to the system, and could therefore result in significant indirect emissions from fossil fuel power plants. Under a GO based system there would be a significant risk that development of a RFONBO industry would result in higher rather than lower net emissions in the 2030 timeframe.

5.2. Guarantees of Origin from new capacity only (GOnew)

One possible adjustment to a GO-based system for assessing the renewability of electricity used for RFONBOs would be to limit the eligible GOs to renewable electricity plants that come into production at the same time as or after the RFONBO facility (referred to henceforth as 'GOnew' certificates). This information is already tracked within the GO system. This would be analogous to the requirement in the RED II that electricity from a direct connection to a grid connected renewable electricity facility may be counted as wholly renewable only if the renewable electricity plant comes online at the same time as or after the RFONBO facility. This would create a bifurcated market in GO certificates, in which there would be a large supply of GOs from pre-existing renewable electricity facilities that would not be eligible to demonstrate the renewability of RFONBO production (though still eligible to be used for green tariffs etc.), and a much smaller supply of eligible GOs from plants coming into operation in the future[8]. Referring back to Figure 3, restricting the supply of GOs eligible to be used to show renewability for RFONBO plants can be seen as a way to shift 'Q_1' to the left, and therefore make it much more likely that the market equilibrium for the price of GOnew certificates would move into the high price regime on the right of the graph.

An obvious question to ask of such an approach is whether the level of demand for GOnew certificates from RFONBO production is actually likely to be large enough to move the price from the low case on the left of Figure 3 to the higher regime on the right of Figure 3. For the period 2020-2030, if the sole use of GOnew is to establish renewability of electricity for RFONBOs, the answer seems likely to be 'no'. Over the course of the decade, we might expect new non-biomass renewables to expand capacity by something of the order of 10% of total EU electricity demand. In contrast, it seems unlikely that even with relatively successful commercialisation RFONBOs would meet more than a fraction of a percent of transport energy demand by 2030. We would therefore expect the supply of GOnew certificates to comfortably exceed demand from RFONBO plants. In this case, using the GOnew approach to claim renewability may deliver no better environmental outcome than using unrestricted GOs.

This picture could change if additional applications were developed for GOnew certificates. One could imagine, for instance, that a GOnew system could be considered in the context of Recital 87 as a basis to link electricity use for electric drive vehicles to additional renewable electricity production, and that adding this demand to the limited demand from RFONBOs could create tension in a the GOnew market.

5.2.i) Additionality under the GOnew system

As with the basic GO system, there would be no guarantee that additional renewable electricity generation would be driven by the GOnew approach. Unless other larger sources of new electricity demand were grouped with demand from RFONBOs, we would expect that certificate supply would significantly exceed demand and that there would be no drive to additional investment. The level of additional renewable electricity production would therefore be determined primarily by market forces.

As with the GO system above, large indirect emissions would be likely under this system, unless demand for GOnews were added in enough applications to exceed the 'natural' rate of renewable power expansion and therefore to bring new capacity to the market.

8 In principle, the price of GOs could diverge into additional tiers based on the provenance date of the GOs and the point of market entry of RFONBO facilities, with the 'newest' GOs attracting the highest potential value.

5.2.ii) Discussion: pros and cons of the GOnew system

Implementation of the GOnew system would be very similar to implementation of the GO system, and likely could use the existing GO accounting frameworks. Given that development of new renewable electricity capacity is likely to significantly exceed plausible demand for electricity from RFONBO facilities, we would anticipate that in practice the GOnew system would have no advantage over the GO system. Only if tension could be introduced to the GOnew market so as to move it to a higher price regime would there be any drive for additional renewable electricity production.

5.3. Guarantees of Origin Plus (GO+)

A more discriminative variation on the GO system is offered by the 'GO+' concept developed by (Timpe et al., 2017). Under the GO+ system, two cases are identified in which electricity used for RFONBO production could be considered renewable and would be more likely to be additional. Firstly, the case of renewable electricity generation from 'new and unsupported' plants. Secondly, the case of 'surplus production that would otherwise have been curtailed'. (Timpe et al., 2017) envisage that competent bodies would be appointed to adjudicate in which cases GO+ certificates for additional production could be awarded.

The first case reflects the GOnew system described above with an added condition that GO+ certificates could only be awarded to renewable electricity projects that do not receive support from public schemes, which would include feed-in-tariffs, renewables obligations, contracts for difference, etc. This approach echoes the option already provided in RED II for Member States to withhold GOs from renewable electricity facilities receiving other public support. (Timpe et al., 2017) note that information is already held in the GO database regarding the year of first electricity production for renewable electricity projects and whether they have received or are receiving government support, and thus the creation of a higher tier of GO+ certificates should not be unduly burdensome.

By allowing certificates to be issued only to electricity from projects not receiving other government support, the GO+ approach seeks to avoid the case whereby RFONBO production could take advantage of capacity developed due to other government policies. Any certificated electricity capacity would therefore have either been actively supported by the option to sell GO+ certificates, or would have to have been viable on market terms alone.

The case of renewable electricity curtailment is somewhat different, as it would require that the RFONBO producer utilising the curtailed electricity was operating at the same time and location as the otherwise curtailed electricity is available. Demonstrating that renewable electricity would otherwise have been curtailed would require coordination with local grid operators and monitoring and reporting (perhaps by administrator request only) of both location specific times of potential curtailment and times of facility operation. Given the desire to maximise operational electrolyser hours, it may be difficult to deliver an economically viable model of RFONBO production based only on curtailment (Timpe et al., 2017). (Christensen & Petrenko, 2017) reports for a model facility that if curtailed electricity was available at zero cost for 4 hours a day the increased effective capital cost would more than offset the saving, so that production would not be economical at the levels of support considered. Some locations may be identifiable with higher rates of curtailment than this, but such bottlenecks may not be stable over time as transmission capacity evolves to meet the requirements of a more distributed generation network. One resolution to this utilisation problem would be to site RFONBO production to take advantage of a renewable electricity bottleneck but use grid electricity (accompanied by GO+ purchases) at other times.

One could argue for the addition of a third class of renewable electricity to be made eligible for GO+ certificates – older projects not receiving government where continued operation would not be financially viable without the revenue from GO+ sales. If such cases were added to the GO+ approach, some form of financial assessment would be necessary, which suggests an approach directly analogous to the additionality assessment under CDM as described above.

5.3.i) Additionality under the GO+ system

At present, it is generally expected that most renewable electricity projects in Europe will continue to require some form of government support to attract investment in the near term (European Commission, 2016a), and therefore it would be reasonable to assume that any project going ahead based only on the market value of electricity and an agreement to transfer GO+ certificates to a RFONBO facility would be reliant on the GO+ income stream to achieve financial viability. In this case, one could argue that the renewable electricity produced would be additional. If projects can only achieve viability through the transfer of GO+ credits, this further implies that the transfer value of GO+ credits would need to be enough to cover any revenue gap from electricity sales. GO+ credits would therefore be expected to be significantly more expensive than GO credits currently are. GO+ certificates issued for electricity supply that would otherwise be curtailed would also be considered to show full additionality. In the case that renewable electricity investments become attractive on market terms alone without the need for support, additionality is less clear, as presumably any given renewable electricity facility trading GO+ certificates to a RFONBO plant could operate successfully without the GO+ revenue stream. The use of otherwise-curtailed electricity would always be additional provided that the assessment of potential curtailment is robust.

For the case that renewable electricity capacity is demonstrably additional, there should be no indirect emissions implication. If renewable electricity deployment becomes fully competitive with fossil power plants, the direct claim to additionality would no longer apply, and therefore some indirect emissions would be possible. However, in the context of such low-cost renewable projects, one would expect that a large fraction of marginal new electricity generation would in any case be renewable, and so the risk of indirect emissions should be rather lower than in the GO or GOnew cases.

5.3.ii) Discussion: pros and cons of the GO+ system

The GO+ system would build on data reporting and tracking mechanisms already present as part of the GO system, but build on it by significantly increasing the potential to use RFONBOs to drive additional renewable electricity capacity development. The link to additional capacity could break in the case that market forces take over from policy as the main driver of new capacity development, but in this case we would expect indirect emissions from non-additional electricity use to naturally limit themselves. GO+ therefore has considerable appeal as a compromise to bring flexibility to the assessment of renewability without undermining environmental performance.

5.4. Guarantees of Origin with a premium (GO^2)

Recital 90 of the RED II identifies two types of additionality for RFONBO production:

1. adding to the renewable deployment;
2. adding to the financing of renewable energy.

The GO+ concept directly addresses the first type of additionality, adding to renewable deployment, by seeking to demonstrate that capacity additions match demand increases. It is also possible to imagine a treatment that seeks to add to the financing of renewable energy without creating a direct correspondence between capacity additions and demand additions.

Such as approach, intended to allow GO certificate sales to contribute to project financing, is seen in the existing GO^2 scheme run by EcoHZ[9]. In this scheme, GO purchasers are invited to voluntarily make an additional payment into a fund to be used to support additional renewable capacity development. One could imagine a government run investment fund being supported in a similar way, or a system by which government could approve private schemes as providing adequate support for renewables financing. Unlike GO+, such a scheme would not create a direct correspondence between additional generation and the amount of electricity consumed by a RFONBO facility, but if certificate purchase was made mandatory for RFONBO producers and the price premium were set at an appropriate level then the revenue from a GO^2 scheme could be planned in such a way as to support a comparable amount of additional capacity to the amount of electricity consumed.

One challenge to a GO^2 system introduced specifically to demonstrate renewability for electricity used to produce RFONBOs would be that the fund would only be formed after RFONBO facilities started producing fuel, and therefore there would be a necessary time delay between the consumption of the electricity and the introduction of additional capacity. It would also be important to consider whether the likely scale of such a fund would be large enough to justify the administrative expense of running an additional funding instrument. For instance, if one or two small RFONBO facilities opened early in the 2020s, the GO^2 revenue from premiums might be quite modest. One way around this concern would be to invest the GO^2 premium into an existing financing mechanism alongside other funds, such as the financing mechanism established in the EU Energy Union Governance Regulation.

5.4.i) Additionality under the GO^2 system

By creating a fund to invest money into new renewable electricity projects, a GO^2 scheme would guarantee that *some* additional renewable power capacity was added to the grid. The amount of capacity that would be added this way would depend on the effectiveness with which the fund was deployed, the rate set for the premium, and the cost of new renewable projects at the time. Subject to these factors, the additional renewable electricity capacity added to the system could be more or less than the amount of electricity consumed to produce RFONBOs.

Assessing (and predicting) indirect emissions under the GO^2 system would be particularly challenging, as it would depend entirely on the efficacy with which the GO^2 fund was able to

9 https://www.ecohz.com/renewable-energy-solutions/go2/

bring new projects forward. If the fund could be managed and the premium set in such a way that more renewable electricity capacity was added to the grid than renewable electricity was consumed by the RFONBO plant, then it should be possible to avoid any net indirect emissions.

5.4.ii) Discussion: pros and cons of the GO^2 system

The GO^2 certificate concept has been developed to allow renewable energy consumers to address concerns that simply purchasing GOs is not enough to deliver real emissions savings. While it has not (to the best of our knowledge) been proposed as a mechanism for assessing renewability of electricity for RFONBO production, it directly and simply addresses the call in the RED II to seek a renewability assessment that would support renewable electricity financing.

The main advantage of the GO^2 idea would be that it would follow the ease of implementation of the GO system, but add a driver for renewable capacity development. The downside of such an approach is that setting the level for a premium would be somewhat arbitrary, and the amount of additional renewable electricity capacity developed need not match the amount of electricity consumed. The main practical problem with such a system is that the establishment of such investment funds by 28 Member States would create a larger administrative burden than simply setting up a certificating system, and that in the early years of RFONBO development this burden may not be proportionate to the rather modest revenues likely to be raised. Politically, such a system might meet resistance as it might be perceived as tokenistic to pay a premium and be allowed to assume renewability, rather than requiring project operators to have direct relationships with renewable power generators.

5.5. Power Purchase Agreements (PPA)

Recital 90 of the RED II specifically identifies power purchase agreements (PPAs) as a potential basis to treat electricity from RFONBO production as wholly renewable. PPAs are defined in the RED II as contracts under which, "a natural or legal person agrees to purchase renewable electricity directly from an electricity producer". Under a PPA, the electricity purchaser agrees to pay a guaranteed price fixed over an agreed period for electricity produced by a renewable power generator. Having a guaranteed sale price reduces risk for the power generator, and in the case of projects obtaining a PPA on future power generation while in development may help with financing.

PPAs can be between two parties sharing a direct electrical connection, or between two parties that are geographically remote. In the latter case power that is supplied to a grid at one location, with offtake of a corresponding amount of electricity at a separate location. For a 'synthetic' (sometimes called 'virtual') PPA, the electricity offtake could be from an entirely separate electricity system – the relationship is entirely financial rather than physical. PPAs can be further divided into agreements with electricity suppliers (utility PPAs, in which case the electricity will be sold on to third parties), and agreements with corporate electricity consumers (corporate PPAs).

In the context of RFONBOs, agreeing a PPA would imply that a RFONBO facility would guarantee an electricity price[10] to a specific renewable energy generator for a significant period (at least

10 In principle, the price need not remain constant throughout the period of a PPA, and could be set

a decade), along with the transfer of any associated GOs (or other GO-type certificates). The use of PPAs as the primary instrument to assess renewability has been proposed by the RFONBO developer Sunfire (Hauptmeier, 2019).

At present, power purchase agreements play several roles in the electricity market. They may allow electricity distributors to agree purchase of renewable electricity from renewable power generators at defined long-term prices, reducing future price uncertainty for both parties. Such a PPA may include provisions relating to grid management and balancing. These PPAs will generally be physical, but in some cases a grid operator will have a synthetic PPA with an electricity producer where a third party owns the intervening infrastructure. Alternately, a 'private wire' physical PPA may be established between an electricity producer and a consumer sharing a direct connection to formalise a long-term power supply agreement. finally, there is the possibility of setting up a synthetic PPA between a power producer and a power consumer across the grid, or potentially even connected to an entirely different electricity system (Dingenen & Reid, 2018). It is this type of PPA that is of most interest here as a basis for renewability claims by RFONBO producers. Different variations of the PPA are detailed further in Table 2.

Table 1. Types of PPA

	Directly connected	Remote	
Utility	PPA between renewable power generator and owner/ operator of local grid	PPA between renewable power generator and electricity supply company that is not the owner/ operator of the local grid	
Corporate	'Private wire' PPA between renewable power generator and directly connected consumer	'Sleeved' PPA between renewable power generator and consumer on same electric system where the consumer pays the producer for 'real time' electric supply along with a fee to the grid operator	'Synthetic' or 'virtual' PPA between renewable power generator and consumer anywhere, where the consumer offers a contract for difference guaranteeing the price received by the producer, without involvement of the grid operator

Under a sleeved PPA, which Dingenen & Reid (2018) identify as a standard structure for these types of agreements in Europe, the renewable energy consumer purchases the electricity generated by the renewable project (or some defined fraction of that electricity), paying the grid operator some form of grid access fee for that electricity to be 'sleeved' across the grid and supplied at the physical location of the renewable electricity buyer's facilities. The precise structure of the contractual agreements may vary by jurisdiction and in relation to

relative to some other market indicators rather than at a single fixed level.

the preferences of the generator, consumer and intermediating utility. It would probably be necessary to set requirements on the nature of a qualifying PPA if these agreements were to be used as the basis of renewability claims. An agreement could potentially include balancing services provided by the grid operator, so that the electricity offtake by the RFONBO plant need not precisely align in time with the electricity generation. A PPA providing such balancing services may be advantageous to the RFONBO facility in terms of optimising operational hours, but for that same reason may not be fully in line with the expectations of the RED II, which calls for temporal and geographic correspondence between renewable electricity generation and renewable electricity consumption.

Under a synthetic PPA, the generator sells power to a local electric utility and the corporate consumer separately purchases electricity from its own local electric utility. The generator and corporate consumer could be on the same electricity system, or could be separated by intervening third party grid infrastructure, or even entirely physically disconnected. In this case, the PPA contract works through a 'contract for difference'. Under this contract for difference, a strike price is agreed for the electricity sold by the power generator to the local utility. If the price received is below the strike price, then the corporate consumer makes up the difference. If the price received is above the strike price, then the power generator pays the excess to the corporate consumer. Under a synthetic PPA, it would be possible for the timing of electricity consumption by the corporate consumer to be coordinated with the timing of electricity generation, but this would not be necessary for the contractual arrangement to work. Allowing renewability to be demonstrated using synthetic PPAs without temporal matching would give a RFONBO producer more flexibility, but would depart from Recital 90 of the RED which calls for temporal and geographical correlation between power generation and power consumption for RFONBOs.

One potential advantage to the RFONBO industry of using PPAs as a basis to assess renewability is that by taking on part of the electricity price risk exposure from the generator a RFONBO facility may have an opportunity to negotiate for a price below expected market rates. RFONBO production would need access to electricity at prices significantly below typical wholesale electricity prices in Europe (Malins, 2017) in order to have a chance of competing with biofuels or fossil fuels, so any opportunity to access lower prices would be welcome.

PPAs between electricity generators and RFONBO project developers (as corporate consumers) would have a different character than PPAs between electricity generators and utilities, due to the nature of the contract participants. Part of the appeal of agreeing a PPA with an institutional investor or a large utility for a new electricity generation project is that they can be considered a reliable customer when raising equity or debt. A PPA signed with an independent RFONBO developer would not be considered to be so reliable, as novel alternative fuel projects are likely to be considered relatively high risk, especially given the poor historical performance of alternative fuel projects in the biofuel sector (Miller et al., 2013). A PPA with a RFONBO developer would therefore be expected to have less value as basis to raise investment than a PPA with a more established business, but may still provide the impetus necessary to develop new projects by reducing the exposure of the generator to variable electricity prices. The capacity of a new alternative fuel enterprise operating a single commercial RFONBO facility to take on the market risk associated with electricity prices might be limited, as in the event that the RFONBO business failed the electricity generator would be left without a PPA. It may therefore be difficult for a RFONBO producer to negotiate a favourable rate unless it was backed by a much larger corporate entity.

Basing the renewability assessment on PPAs would require that relevant regulatory agencies develop oversight capacity to assess the paperwork related to PPAs (establishing that any reported agreements are real and meet any conditions placed upon them by legislation). The correspondence between the quantity of renewable electricity purchased under a PPA and the amount of electricity consumed in RFONBO production would also need to be monitored. If conditions are placed on geographical and temporal correlation of production and consumption this would also need to be monitored. Utilities hold the data necessary to make these assessments, but it would be important to establish the basis upon which regulators could have access to that data (or upon which a system of independent verification could be implemented). A PPA-based system would therefore represent a greater administrative challenge for Member States than a GO or GO+ system for which basic reporting infrastructure is already in place.

5.5.i) PPA for curtailed renewable electricity?

Existing PPAs allow renewable power from a specified generator to be purchased by a specified consumer. It is possible in principle to imagine a novel form of PPA in which an electrical utility would contract to supply a certain quantity of curtailed electricity to a RFONBO facility at a given price if and when such an amount of electricity curtailment occurred (a type of contract for grid balancing services). We are not aware of examples of precisely this contractual structure, but if PPAs were made central to demonstrating renewability under RED II such curtailment PPAs could allow additional renewable electricity from avoided curtailment to be used in the system.

5.5.ii) Additionality under the PPA system

An important difference between PPAs and GOs is that a PPA is a bilateral long-term agreement that requires a relationship between two specific legal entities, whereas GOs can be traded at will on a market. Entering into a PPA therefore represents an expression of intent to support a project on a long-term basis. PPAs have been used in the past as a tool for larger utilities and investors to support renewable electricity capacity development while hedging against electricity price variability (Powers & Haddon, 2017). By guaranteeing future revenue streams, PPAs can provide a basis to support investment in projects, and thus may deliver additional renewable energy capacity.

Entering a PPA would not directly affect the eligibility of a renewable electricity facility to access government support, and therefore PPAs would not affect whether electricity used for RFONBOs from being incentivised by other instruments or counted towards other targets. PPAs could therefore be arranged equally with new renewable power facilities in development, with facilities that are already viable on market terms (e.g. existing hydro power) or with facilities that are made financially viable by other government support. For facilities that would be expected to be economically viable even without a PPA, the existence of a PPA would not prove that the generation was additional. Projects with good underlying economics would potentially be able to offer PPAs at lower offtake prices. In the absence of additional restrictions on which PPAs would be eligible, RFONBO project operators may preferentially seek to enter PPAs with such already-viable electricity generators to access lower prices. Such a dynamic would tend to further reduce the potential of RFONBO production to support additional renewable electricity generation.

While the use of a PPA *could* in principle support additional renewable capacity deployment, without additional restrictions on the types of projects with which PPAs would be considered, or some direct additionality assessment for projects entering PPAs, this cannot be guaranteed. The PPA approach has more potential to deliver additional capacity than the simple GO or GOnew approaches, but without additional criteria a PPA approach additionality would certainly not be assured. A 'PPA+' approach that would address some basic additionality concerns is discussed below.

As in other systems, indirect emissions would arise under a system of PPAs if the partner renewable electricity project is not additional, and if fossil fuels are part of the marginal electricity supply.

5.5.iii) Discussion: pros and cons of the PPA system

A PPA-based system is favoured by some potential project developers, and would create direct relationships between RFONBO project developers and renewable electricity project developers. Despite creating these relationships, it is not clear that the use of PPAs alone would necessarily drive additional project development, as an agreement could as easily (or even more easily) be reached with an existing viable renewable electricity project as with a project under development in need of the support of a PPA to deliver investment. A simple PPA system would therefore be at risk of having significant associated indirect emissions. Below, we consider requirements that could be placed on eligible PPAs to boost the chance of additionality (see below).

5.6. Power Purchase Agreements plus (PPA+)

Analogously to GO+, a PPA+ system could be developed in which the basic requirement to demonstrate a PPA would be combined with further requirements to provide evidence that additional renewable electricity is supported. A PPA+ approach would include:

- A requirement for a PPA agreement between generator and RFONBO operator;
- A requirement for GO+ certificates (as described above) to accompany all supplied electricity (i.e. electricity would be from 'new and unsupported' generation capacity or avoided curtailment).

Combining GO+ certificates with appropriate PPA contracts would significantly increase the likelihood that the renewable electricity projects contracted with the PPAs would be additional, as contracts would need to be formed with new power projects not receiving other forms of government support. As noted in the section above on PPAs, one potential barrier to successfully delivering additional renewable electricity through this type of arrangement is that independent RFONBO project developers may not be considered reliable long-term customers, reducing the value of these PPAs to project developers. There is no simple solution to that problem, but it can be assumed that strong support schemes in Member States would be required to make PPAs with RFONBO plants more credible.

As noted above for GO+, limiting PPAs to new renewable power facilities and curtailment could potentially rule out some genuinely additional cases. For example, Fischer et al. (2019) notes that some older facilities lapsing out of other government support schemes may need additional support to continue generating.

5.6.i) Additionality under the PPA+ system

Adding the GO+ requirements to the PPA-based renewability assessment system should increase the likelihood that the partner renewable electricity project is genuinely additional, and therefore reduce the risk of indirect emissions.

5.6.ii) Discussion: pros and cons of the PPA+ system

The PPA+ system briefly outlined above adds aspects of the GO+ system to the 'pure' PPA approach discussed in the previous section. This expanded PPA-based approach would be much better equipped to meet the aspiration of the RED II that additional renewable electricity should be used for RFONBO production.

6. Discussion

RFONBOs have great potential in principle, but successfully developing a RFONBO industry in the EU while delivering real CO_2 emissions reductions is not an easy task. The high expected cost of RFONBO production and the lack of a specific target in the RED II can be expected to make developing significant capacity during the 2020s challenging, and in this context there will be a natural desire on behalf of both the industry and policy makers to avoid putting additional cost barriers in the way of progress. The other side of the coin is the reality that using electricity for fuel synthesis has the potential to significantly increase net emissions unless additional renewable electricity is consumed. If the regulatory regime for RFONBOs cannot ensure that additional renewable electricity capacity is used to power new RFONBO plants, the industry is likely to increase rather than decrease CO_2 emissions across the system as a whole – at current grid-average GHG intensity for EU electricity, produced RFONBOs would have a climate impact three times higher than a fossil fuel alternative.

As it stands, the methods to establish renewability for RFONBOs as laid down by the RED II may fall short on two counts – creating barriers to deployment that may not be necessary, while failing to guarantee additionality of renewable electricity production. Setting renewability based on the grid average non-biomass renewable content would effectively preclude RFONBO production in most countries, while not ensuring additionality in countries in which production might be viable. Requiring a direct connection to a single renewable electricity facility may encourage the development of additional projects, but would impose significant costs by preventing maximum utilisation of electrolysers.

There is then a strong case to add a third basis to identify electricity for RFONBO production as wholly renewable. The existing system of GO certificates has been used for several years as a basis to make claims of renewable energy use for consumer electricity supply and in corporate carbon accounting, but has been criticised in the policy literature for giving credit without delivering real environmental gains. The price of GO certificates is currently much too low to support investment in new projects. It is clear that simply retiring GOs for consumed electricity will not drive additional renewable electricity capacity development, and will not be enough to deliver a truly low-carbon RFONBO industry. Adjustments to the GO system have been suggested that could make it more suitable for the purpose at hand. Limiting the set of eligible GOs to those generated by new projects that do not receive support from other government instruments (GO+) could create a higher value tier of certificates that could actually support project development.

Beyond a pure book and claim system similar to GOs, a system could be considered requiring direct financial relationships between RFONBO producers and renewable electricity generators, through power purchase agreements (PPAs). Providing guaranteed customers and electricity prices to new facilities could have a material role in boosting project development. A requirement to form bilateral PPAs could be coupled to a certificate system based on the GO+ concept to deliver a much more robust form of governance for RFONBO production. Of the flexible systems considered in this paper, such a 'PPA+' system appears to have the most promise as a way to maximise the likelihood that additional renewable electricity capacity would be added to meet demand from RFONBO facilities.

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