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Unpacking the legal conundrum of nature-based soil remediation and sustainable biofuels production in the European Union

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A B S T R A C T

The fight against soil contamination and the development of sustainable fuels constitute major environmental and climate change objectives under the European Green Deal. At the same time, the uptake of nature-based solutions is increasingly advocated in the European Union as viable techniques to enhance soil ecosystem services while addressing the soil vs. food vs. energy conundrum to achieve the UN Sustainable Development Goals and the European Green Deal objectives. This contribution deals with unlocking the potential of *phytoremediation* both a soil remediation technique and a source of sustainable feedstock for advanced biofuels. Phytoremediation consists of the use of plants and their associated microbes to extract, volatilize, stabilize, or degrade soil pollutants. Furthermore, phytoremediation's by-products may be used to develop advanced, low indirect land use change biofuels thus contributing to the EU's climate change mitigation objectives.

The value chain entailed in the deployment of phytoremediation techniques and recovery of phytoremediation's output materials for biofuels production faces an array of legal and policy roadblocks in the European Union. Importantly, such barriers relate both to material legal obstacles, policy fragmentation and lack of a holistic approach towards complex processes. This contribution aims to provide a comprehensive overview of such legal and policy roadblocks with a view to champion the embedding of phytoremediation in the existing EU legal framework also in relation to the development of low-Indirect Land Use Change biofuels.

1. Introduction

Soils lie at the intersection of all the three major global challenges worldwide: climate change, biodiversity loss and pollution. Yet the manifold ecosystem functions of soils are deteriorating at a relentless pace due to land-use change, erosion and loss of soil organic carbon, thus generating positive feedback loops in terms of loss of carbon sinks, loss of biodiversity and enhanced threat to human health (FAO and UNEP, 2021). Moreover, compelling governance trade-offs are emerging between soil conservation and management and other key policies and practices aimed to address climate change, primarily sustainable fuels production (Hannam, 2021). Biofuels as sophisticated alternative energy sources are a key enabler to both achieve greenhouse gases emissions reductions, enhance energy security and rural development thus contributing to the obtainment of a wide range UN Sustainable Development Goals (UN SDGs) (Blair et al., 2021). At the same time, large-scale development of biofuels provides adverse impacts in terms of land use and food prices (FAO, 2008). Such conflicts emerge in light of Indirect Land-Use Change (ILUC) due to the expansion of monocultures for the production of biofuels – primarily for the aviation and shipping sector (McCarl, 2017).

The land vs. energy nexus is heavily surfacing in the European Union (EU) as a major policy and regulatory issue. Since 2019, the EU has been adopting wide-ranging policies under the umbrella of the European Green Deal (EGD). As such, the EGD aims to address soil protection against all the three above major environmental threats in a holistic way (Panagos et al., 2022). However, the implementation of the EGD still faces major challenges due to policy integration, silos-thinking and adequate regulation of complex value chains and policy face-offs (Krämer, 2020).

Against this backdrop, Nature-based Solutions (NbS) may provide a win-win solution to both enhance soil remediation thus enhancing soil ecosystem services while providing low-ILUC sustainable fuels. NbS can be defined as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (IUCN, 2020). The EGD explicitly acknowledges NbS as a valuable tool for both climate change mitigation and

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adaptation (European Commission, 2019a). More specifically, phytoremediation has been heralded as a promising NbS technique, which deploys plants and their associated microbes to stabilise, degrade, volatilise and extract soil pollutants while providing feedstock for conversion into biofuels and other by-products, thus contributing to multiple EGD objectives (Raklami et al., 2022; Guarino et al., 2020; Yanitch et al., 2020; Gavrilescu, 2022).

This article charts the current legal and policy regime in the EU throughout the value chain of phytoremediation and post-remediation management in terms of phytoremediation's output materials recovery for biofuels production. The use of biomass after phytoremediation has been suggested since a relatively long time (Banuelos, 2006). However, comprehensive knowledge about domestic and international policies concerning these issues is still lacking (Song et al., 2016). We thus aim to analytically outline the legal face-offs present in relation to complex yet inherently sustainable value chains to achieve multiple environmental objectives of the EGD and the UN SDGs. To this end, it first unpacks the role of NbS in the European Union in relation to the environmental and climate change mitigation EGD objectives. Second, it analyses phytoremediation as an enabling solution for soil remediation and advanced biofuels production. Third, it charts the legal and policy framework as hampering the full implementation of phytoremediation and output materials conversion thereof in the EU. Last, it provides a set of legal issues for further critical legal appraisal.

2. Nature-based-solutions and the land vs. energy conundrum in the EU: A policy overview

Soils are facing multiple threats stemming from a multitude of environmental pressures. In Europe, the precise impacts of climate change on soil degradation in Europe are still uncertain (Kovats et al., 2014). The two major threats identified to soil ecosystems relate to soil contamination and loss of Soil Organic Matter (SOM). The number of sites where potentially polluting activities have taken place in Europe now stands at approximately three million, whereas the total SOM estimated to be stored across EU-27 soils accounts for between 73-79 billion tonnes CO_2 (EEA, 2020). Severe losses are due to land-use changes for several activities including waste disposal, industry, agriculture and bioenergy (Liederkerke et al., 2014). Among such activities, the production of biofuels has gained attention in terms of its asserted environmental and climate impacts. According to a recent study, direct and indirect land-use change due to increasing cropland expansion for biofuels production in line with the EU adopted targets would result in the outsourcing of more than 400 million tons CO_2/year losses (Searchinger et al., 2022).

The EU has upheld clear-cut commitments to protect soils under the Kunming-Montreal Global Biodiversity Framework (GBF) adopted at the UNCBD COP 15 in November 2022 (UNCBD, 2022). Accordingly, effective conservation and management of at least 30% of the world's lands should be achieved - with a specific focus on their ecosystem functioning and services – as well as restoration of at least 30% of degraded terrestrial ecosystems (UNCBD, 2022). The GBF framework complements the land-degradation neutrality target under the UNCCD by 2030 and is envisioned under the broader objectives of the UN Sustainable Development Goals (SDGs).

The EU is committed to ensure a high level of protection of the environment pursuant to Article 191 of the Treaty of Functioning of the European Union (TFEU). This general objective can be referred to soils both as a natural resource threatened by contamination and as a tool to fight climate change through SOM (Fermeglia, 2022).

Therefore, the EGD comes with an ambition to make Europe the first climate-neutral continent while achieving a net-zero pollution by 2050 (Montanarella and Panagos, 2021). Therefore, a target of 14% on the uptake and utilization of biofuels to achieve deep decarbonization of the transport sector, as backed by a minimum share of 3.5% advanced biofuels.[1]

At least three main elements come into play with regard to the policy uptake of NbS in the European Union.

First, the net-zero pollution action plan mandates to create a toxic-free environment, which includes soils health in terms prevention and minimisation of pollution as well as remediation as a central point of action (European Commission 2021a; Heuser and Itey, 2022).

Second, the EU Biodiversity Strategy for 2030 aims to ensure biodiversity loss is combated and ecosystems conservation status is improved (European Commission, 2020a). NbS are marked in the Biodiversity Strategy as essential to both maintaining and increasing biodiversity while enhancing SOM and soil resilience (European Commission 2019a; OVAM, 2019).

Third, the EU Soil Strategy for 2030 has stepped up the EU's ambition towards a harmonized legal framework for soil protection, remediation and management (Panagos and Montanarella, 2018). It moreover aims to overcome the asserted legal fragmentation existing both across EU policy silos and member States national soil legislation (Paleari, 2017; Stankovics et al., 2018). Within the context of the Soil Strategy, the upcoming Soil Health Law will aim to achieve good soil quality status (European Commission, 2021). NbS can substantially contribute to those objectives by restoring soil's health in a cost-effective and ecosystem services-oriented manner (European Commission, 2021a). Furthermore, in the context of soil remediation, NbS may contribute to curb land use change by generating organic feedstock for advanced biofuels which can be used for other energy production purposes.

3. Phytoremediation as a nature-based-solution for soil remediation and biofuels production

Phytoremediation is a nature-based soil remediation technique that use plants for treating polluted soils (FAO and UNEP, 2021). It is widely understood as the "bioremediation of contaminated soils by using plants or crops, applicable for the removal or degradation of organic and inorganic pollution in soil, water and air" (Vanheusden, 2017). It is important to highlight that using contaminated soils to produce energy crops reduces the pressure on fertile soils and eliminates competition with food production (Rowe et al., 2009). Furthermore, the use of native species as bioenergy crops would limit the introduction of non-native species (Bernal et al., 2019). Cultivation of edible crops in contaminated soils is part of justifiable concerns regarding human and animal health (Prasad, 2015). Therefore, protection against eating by animals is an important step in order to block the entrance of contamination into the food chain (OVAM, 2019). Monitoring is also an important tool that must follow the phytoremediation process to show if contamination in crops exceeds the permissible level.

Compared to traditional remediation techniques, phytoremediation is characterized by climate-friendly (Ganesan et al., 2020), small environmental footprint and low operational costs (Guidi Nissim et al., 2023; O'Connor et al., 2019). Phytoremediation entails different strategies depending on the pollutants to be addressed. According to the report of the European Environment Agency, the most frequent soil contaminants at investigated sites in Europe are heavy metals and mineral oil (EEA, 2023). The identification of the correct phytoremediation strategy is crucial to adequately combat inorganic pollutants, and in particular heavy metals (Singh et al ., 2011). The most effective phytoremediation strategies against heavy metals are phytoextraction, phytovolatilization, phytostabilisation and rhizofiltration (Parveen et al, 2022), albeit only

[1] European Parliament and Council Directive on the promotion and use of energy from renewable sources, no. 2018/2001/EU.

phytoextraction and phytostabilisation are considered as the most reliable (Laghlimi et al., 2015). Phytoextraction, also knowns as phytoaccumulation, uptakes pollutants by the roots and accumulates in the aboveground biomass (Zeremski et al., 2021). Acccording to the literature, certain plant species are recommended for phytoextraction based on the different kind of heavy metals: for example, sunflower (*Helianthus annuus*) (Rahman et al., 2016; Marchiol et al., 2007) and Chinese brake fern (*Pteris vittata*) (Rahman et al., 2016; Ma et al., 2001) for As; willow (*Salix viminalis*) Cd, Zn, Ni, Pb, and Cu (Rahman et al., 2016; Greger and Landberg 1999; Borišev et al., 2009); Indian mustard (*Brassica juncea*) for Pb (Rahman et al., 2016; Blaylock et al., 1997).

On the other hand, phytostabilisation is the process of stabilization of inorganic contaminants (Parveen et al, 2022). Phytostabilisation is not considered a clean-up technology of contaminated soils but mechanism that limits potentially toxic contaminants (Fermeglia and Perišić, 2023; Vangronsveld, 2009).

Phytovolatization shows certain results regarding selenium, where after sequestration and conversion of the inorganic selenium into volatile organic, non-harmful components that can be volatilized without risk (OVAM, 2019; Banuelos et al., 2002). While this is not the case regarding mercury (OVAM, 2019).

Overall, to implement phytoremediation leads to several environmental and health benefits in terms of conversion of previously contaminated land into fertile soils to be used for agricultural purposes (Alvernia and Soesilo, 2019; Mahar et al., 2016).

Phytoremediation entails a complex value chain, which can be summarized in the following main elements:

- Site characterization.
- Full-scale phytoremediation, which in turn includes crops selection and harvesting.
- Phytoremediation output materials recovery and management, including transport.

Furthermore, an innovative and truly circular approach aims to combine phytoremediation implementation and drop-in biofuels production from its feedstock. The following components must therefore be added to the above value chain:

- Biomass conversion and biofuels production.
- Biofuels distribution and end use.

The above key steps of the value chain addressed in this study are outlined in Fig. 1 below.

Several legal issues arise in the EU throughout the above value chain for phytoremediation and related biofuels production. Such issues relate to a broad array of policy areas, ranging from (domestic) soil legislation to EU legislation on waste management, transport and biofuels production, as displayed in Fig. 2 below.

The following Sections will focus on legal issues identified in the three elements of the above value chain:

- Phytoremediation implementation, including site characterization and full-scale remediation.
- Phytoremediation's output materials recovery and management.
- Phytoremediation's output materials conversion to biofuels.

4. Policy and legal obstacles for phytoremediation in the EU down the phytoremediation and biofuels production value chain

4.1. Phytoremediation implementation: Invasive alien species and GMOs regulation

The characteristics of selected plants for phytoremediation play a crucial role. The selected plants should preferably have the following characteristics: fast growth, capability to accumulate large biomass, rapid propagation, tolerance to soil conditions and climatic (Pandey et al., 2012, 2015).

The process of plants selection for phytoremediation comes at odds with the regulation on alien species and Genetically Modified Organisms (GMOs). There is contrasting scientific evidence on the approach to invasive species for phytoremediation purposes. For, invasive alien species might impact local ecosystem while however fostering the absorption of contaminants *in situ* (Trueman and Erber, 2013). Empirical evidence shows that the use of non-native plants might be initially profitable when weighted against the economic costs and externalities stemming from their uprooting in an hosting environment (Pandey and Souza-Alonso, 2019). Yet invasive alien species might also present a severe threat to human health and wildlife (Hulme, 2014). As underscored by the EU Biodiversity Strategy for 2030, 354 sites are currently under threat from invasive alien species (European Commission, 2020a); whereas according to IPBES, invasive alien species are one of the most relevant drivers of environmental threats to biodiversity together with climate change, land and sea use change, overexploitation of resources and pollution (IPBES, 2019).

International and European legal instruments regulate the introduction of invasive alien species. First, Article 8(h) of the UN Convention on Biodiversity (UNCBD) aims to "prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species". Moreover, in the Kunming-Montreal Global biodiversity framework, attention to invasive species is dedicated in Target 6, whereby the rate of introduction and establishment of invasive alien species should be reduced by 50% by 2030.[2]

With regard to EU law, Article 22(b) of the Habitats Directive (no. 92/43/EEC) imposes an obligation to "ensure that the deliberate introduction into the wild of any species which is not native to their territory is regulated so as not to prejudice natural habitats within their natural range or the wild native fauna and flora and, if they consider it necessary, prohibit such introduction". In addition, the EU Invasive Alien Species Regulation (no. 1143/2014/EU) enlists all invasive alien species deemed of concern for habitats protection and human health. This represents a limitation regarding the array of available plants for phytoremediation in its initial stage.

At the same time, genetic engineering of plants can improve plants' phytoremediation efficiency, for example, accumulation, tolerance and detoxification capacities of high biomass and rapidly growing plants (Verbruggen et al., 2009). Release of GMOs is problematic since it opens various concerns regarding the environmental impact and public and government resistance (Schwitzguébel, 2001). Those concerns seem to be justified since every application of GMOs technology entails unpredictability (Khan et al., 2020). As in the case of invasive alien species, the uptake of GMOs may lead to advantages with regard to the remediation potential while delivering significant impact over the native organisms (Saxena et al., 2020; IUCN, 2004; Prakash et al., 2011).

Under EU law, GMOs are defined as "an organism, with the exception of human beings, in which the genetic material has been altered in a way that does not occur naturally by mating and/or natural recombination; within the terms of this definition: (a) genetic modification occurs at least through the use of the techniques listed in Annex I A, part 1; (b) the techniques listed in Annex I A, part 2, are not considered to result in genetic modification."[3] The EU Genetically Modified Organisms Directive operates in accordance with the precautionary principle under Article 191(2) TFEU. Accordingly, it aims to protect human health and the environment from deliberate release into the environment of GMOs

[2] Kunming-Montreal Global biodiversity framework, Draft decision submitted by the President, CBD/COP/15/L.25.

[3] Article 2(2) of the Directive 2001/18/EC of the European Parliament and of the Council of 12 March 2001 on the deliberate release into the environment of genetically modified organisms.

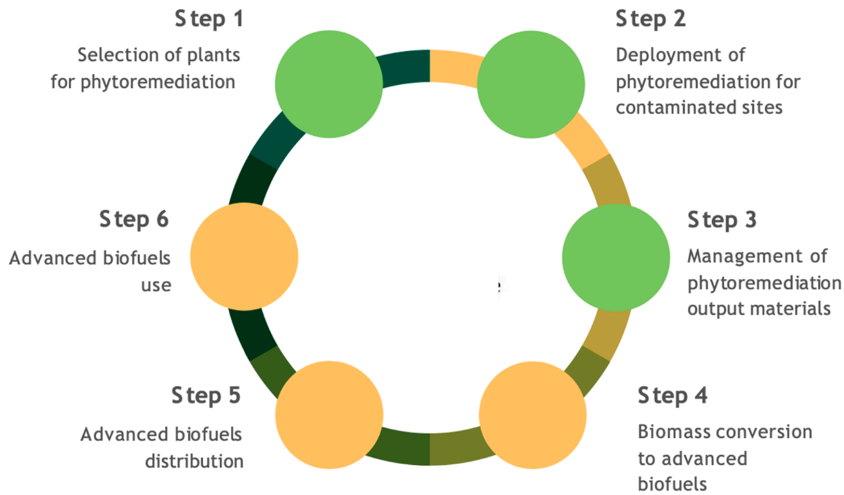

Fig. 1. Stepwise approach to deployment of phytoremediation and recovery of output materials for biofuels conversion. Source: Authors.

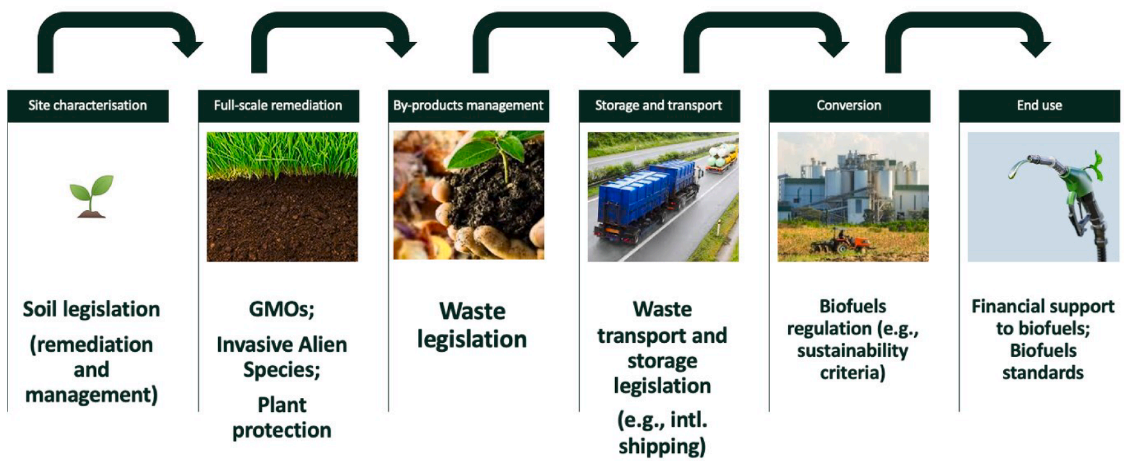

Fig. 2. Legal issues down the supply chain of phytoremediation and biofuels conversion. Source: Authors

as well as placing them on the market.[4] In recent years, biotechnological techniques brought the development of new plant breeding techniques also known as New Genomic Techniques (NGTs) (Commission Staff Working Document, 2021). NGTs are defined "as techniques that are capable of altering the genetic material of an organism and that have emerged or have been mainly developed since 2001" (European Commission, 2021). The crops produced using some of these new plant breeding techniques cannot be distinguished from their conventionally bred counterparts (Lusser et al., 2011). Therefore, the issue as to the inclusion of NGTs under the scope of GMOs legislation is important for phytoremediation techniques. In a recent judgment, the Court of Justice of the European Union (CJEU) ruled out NGTs as falling under the category of GMOs within the meaning of Article 2(2) of Directive 2001/18/EC.[5]

Notwithstanding, it is evident that the above strategic preliminary decisions regarding phytoremediation techniques must be adopted by carefully appraising potential threats to biodiversity, human health and animal health; only in that matter decisions can be brought towards better conservation and restoration (Cadotte et al., 2011).

4.2. *Phytoremediation output materials recovery and management: Waste legislation*

If compliant with the relevant legislation, the selected crops must be planted for phytoremediation. The choice at this stage depends on the plants' resistance and yield potential in the contaminated environment. By deploying the phytoextraction strategy, the logical premise is that the contaminants are now in the plant's harvestable parts, i.e. biomass. Therefore, the contaminated biomass could be legally considered as toxic or hazardous waste (Wani et al., 2023). Proper handling of contaminated biomass and its disposal is of pivotal importance in order to avoid secondary pollution, i.e. contaminating soil again. Several disposal options exist that would ultimately influence the definition of recovery output materials: composting, compaction, pyrolysis, leaching, and incineration (combustion and gasification) (Kovacs and Szemmelveisz, 2017).

Contaminated biomass is deemed as waste under the EU Waste Framework Directive (WFD), which includes in its scope any "… straw and other natural non-hazardous agricultural or forestry material used in farming, forestry or for the production of energy from such biomass through processes or methods which do not harm the environment or

[4] Directive 2001/18/EC, Article 1.

[5] See Case C-528/16, *Confédération paysanne and Others*, ECLI:EU:C:2018:583 para. 30.

endanger human health".[6] The qualification as waste under the WFD is a crucial legal element as it would lead to the obligation to discard and disposal upon the waste producer. However, the WFD also allows for the contaminated biomass to escape the qualification as waste by acquiring the status of by-products or End-of-Waste (E-o-W). Such qualification can take place under a set of specific criteria, which comprise the following:

- That the substance or product will be used for specific purposes under a normal industrial practice.
- That there will be an economic valorisation of the substance or product within an existing market.
- That the re-use of the substance or product will be legal and not lead to further environmental and/or health impacts.

Among the above criteria, a key element that could trigger the qualification of phytoremediation feedstock as by-products or E-o-W relate to the goal of their future use. In fact, if destined to biofuels production, there is no intention for contaminated biomass to be discarded but to be economically valorised (Khan et al., 2023). This falls squarely within the criteria set out under the WFD. As recently clarified by the Court of Justice of the European Union, when deciding upon the qualification of a product or substance under the WFD (including excavated soils) public authorities must duly take into account the circular economy and environmental objectives of the WFD, as well the broader objectives of EU's environmental policy.[7]

The extension of the actual feedstock contamination plays also a key role for this assessment process as the WFD explicitly rules out of the by-products and E-o-W definition any substance or product that leads to significant impact to human health and the environment (Article 5(1) WFD). However, such potential should be duly appraised against the use of biomass as throughput for biomass production, which ultimately leads to negligible emissions into environmental media.

Another particular barrier relates to the criterion of "normal industrial practice". Yet under normal industrial practice, products or substances may be dried, washed, filtered, and modified in shape and size. Similarly, it is allowed to add materials necessary for further use or to carry out quality control (European Commission, 2012a). Thus, an elastic interpretation looking at the overall objectives of the EGD and the WFD should be adopted to assess phytoremediation output materials management and processing as normal industrial practice with regard to the value chain displayed above throughout the production of advanced biofuels.[8]

4.3. Biomass conversion: Sustainability criteria for biofuels

Advanced drop-in biofuels are liquid hydrocarbons functionally equivalent and as oxygen-free as petroleum derived transportation blend stocks (fuels). The EU Renewable Energy Directive (no. 2018/2001/EU, RED II) defines advanced biofuels as biofuels produced out of specific feedstocks including wastes, residues, co-products and some selected primary products, yet overall guarantee a meaningful GHG savings through their life-cycles (Article 29). The major competitive advantage of advanced biofuels is that they can completely replace conventional petroleum fuels, whether gasoline, diesel, or jet fuels while ensuring cradle-to-pump GHG and environmental benefits (Mizik and Gyarmati, 2022). The general sentiment towards advanced biofuels is yet not positive due to ongoing debates about the sustainability of food-crop-based biofuels. Furthermore, it is important to stress that biofuels production is mainly a policy-driven market that is highly sensitive to dedicated policy support (IRENA, 2019). The lack of regulatory framework and financing mechanisms for the biomass price fluctuations can be considered as dominant gaps in policy hampering biomass logistics (Panoutsou et al., 2021). The resulting indecisiveness by consumers in turn hampers the development of better performing biofuels upstream (IISD, 2013). Against this backdrop, the sustainability criteria set in the EU by the RED II, the Fuel Quality Directive (no. 2009/30/EC) and the ILUC Delegated Regulation (no 2019/807/EU) and complemented by *ad hoc* voluntary certification schemes could enhance consumers' confidence in advanced biofuels. However, voluntary schemes are not yet harmonised and fragmented, thus increasing consumers' uncertainty towards advanced biofuels (Mai-Moulin et al., 2021). In the EU, there are currently 13 certification schemes for biofuels recognised by the European Commission (European Commission, 2019). Since the road vehicle and oil industry work inherently at a multinational scale, the adoption of EU-wide or at least mandatory national certification schemes may be seen as a major barrier to the uptake of advanced biofuels by end-users.

Relevant barriers to the proper uptake of advanced biofuels conversion thus arise primarily from the lack of dedicated policy framework and support both at the supra-national and national level. Therefore, it is crucial to ensure the need for long-term stable policy support to provide stability and security for the industry. In this respect, the proposed revision of the RED II should embrace the objective of addressing "[F]eedstock for advanced biofuels and biogas for transport, for which technology is more innovative and less mature and therefore needs a higher level of support" also in light of the overarching EGD objectives related to circular economy and the fight against pollution in soil, water and air (European Commission, 2021).

5. Discussion and conclusions

Whilst the European Green Deal points to a holistic and coordinated approach to environmental pressures and GHG sources, this research has identified a set of legal and policy issues, which do not allow for the implementation of complex, fully circular value chains to address policy face-offs. Where the above Sections have focused on a selected set of legal issues, overall we have identified at least 14 pointed legal and policy issues in the current EU and domestic regulatory framework. Such barriers are outlined in Table 1 below.

Among the above relevant elements, the following retain utmost importance in view of the scalability and marketability of the value chain addressed in this contribution as a subject for further enquiry and fundamental legal research.

First, the lack of harmonised legislation for soil protection at supranational and national level hinders the up-scaling of nature-based, sustainable soil remediation methods while lock-in current soil remediation technologies.

Second, the elastic and in some instances unclear framework for the use of GMOs and invasive alien species faces phytoremediation deployers with uncertainties in the – key – process of crops selection when appraising the potential advantages and disadvantages thereof in terms of remediation potential vs. external ecosystem and health impacts.

Third, waste legislation can provide meaningful obstacles to the circular approach in the carrying out of phytoremediation recovery of output materials, with specific regard to the management of phytoremediation's biomass for advanced biofuels production purposes. Moreover, the key legal issue as to the classification of contaminated biomass as End-of-Waste or by-products entails significant consequences for the transport and storage, which however go beyond the scope of this research.

Fourth, the lack of a coherent, stable policy framework for biofuels curtails the attractiveness of the advanced biofuels market for investors, thus ultimately hindering the creation of economies of scale and the full

[6] See Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste, Article 2(f).

[7] Case C-238/21, *Porr Bau GmbH v Bezirkshauptmannschaft Graz-Umgebung*, ECLI:EU:C:2022:885, para. 58.

[8] See Case C-358/11, *Lapin elinkeino*, ECLI:EU:C:2013:142, para. 65.

Table 1
Legal obstacles to phytoremediation and biofuels production value chain. Source: Authors

Legal and policy barrier	Relevant steps of the value chain	Activities affected
Phytoremediation implementation		
Lack of comprehensive soil legislation dealing with nature-based remediation techniques and specifically addressing phytoremediation.	Step 1 Step 2	Adoption of phytoremediation
Limitations on imports of certain invasive alien species.	Step 1	Crops selection
Limitations to the use of certain fertilisers.	Step 2	Crops yielding
Limitations to the use of certain GMOs or NGTs for phytoremediation.	Step 1 Step 2	Crops selection Crops yielding
Classification of phytoremediation biomass as End-of-Waste or by-products according to waste legislation.	Step 3	Crops utilisation after phytoremediation
Advanced biofuels production		
Lack of harmonised criteria for sustainable farming practices in relation to energy crops.	Step 4	Feedstock supply
Lack of comprehensive approach to carbon farming and inclusion of targeted promotion of restorative practices for increase of carbon stocks.		
Lack of dedicated regulatory schemes for non-food advanced biofuels.		
Lack of comprehensive international standards and mandates for advanced biofuels for shipping and aviation.	Step 4	Biomass conversion
Lack of financial support to advanced biofuels.	Step 4 Step 5	Biomass conversion Distribution
Lack of economic incentives to purchase of advanced biofuels.	Step 5 Step 6	Distribution
Lack of harmonised certification schemes for sustainability criteria of biofuels.	Step 5 Step 6	End-use
Competing domestic financial support to petroleum fuels.	Step 6	End-use

uptake at the expected degree. Policies at the supra-national and national level should prioritise biomass supply with low-iLUC impact and support biofuels production for transport that have few alternatives to achieve decarbonization (such as shipping and aviation).

Fifth, comprehensive certification schemes and criteria for biofuels production that take into full account ILUC beneficial impacts generated by sustainable feedstock inputs are needed to maximise the benefits of generating nature-based soil remediation biomass and producing advanced biofuels.

Sixth, the current, still extensive amount of economic support provided to traditional fossil fuels hamper the large-scale development of biofuels, including advanced biofuels.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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