BIOMETHANE INDUSTRIAL PARTNERSHIP

FEEDSTOCK PRODUCTION ON MARGINAL AND CONTAMINATED LAND

AN EU-WIDE POTENTIAL ASSESSMENT

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BIP Europe
Biomethane Industrial Partnership

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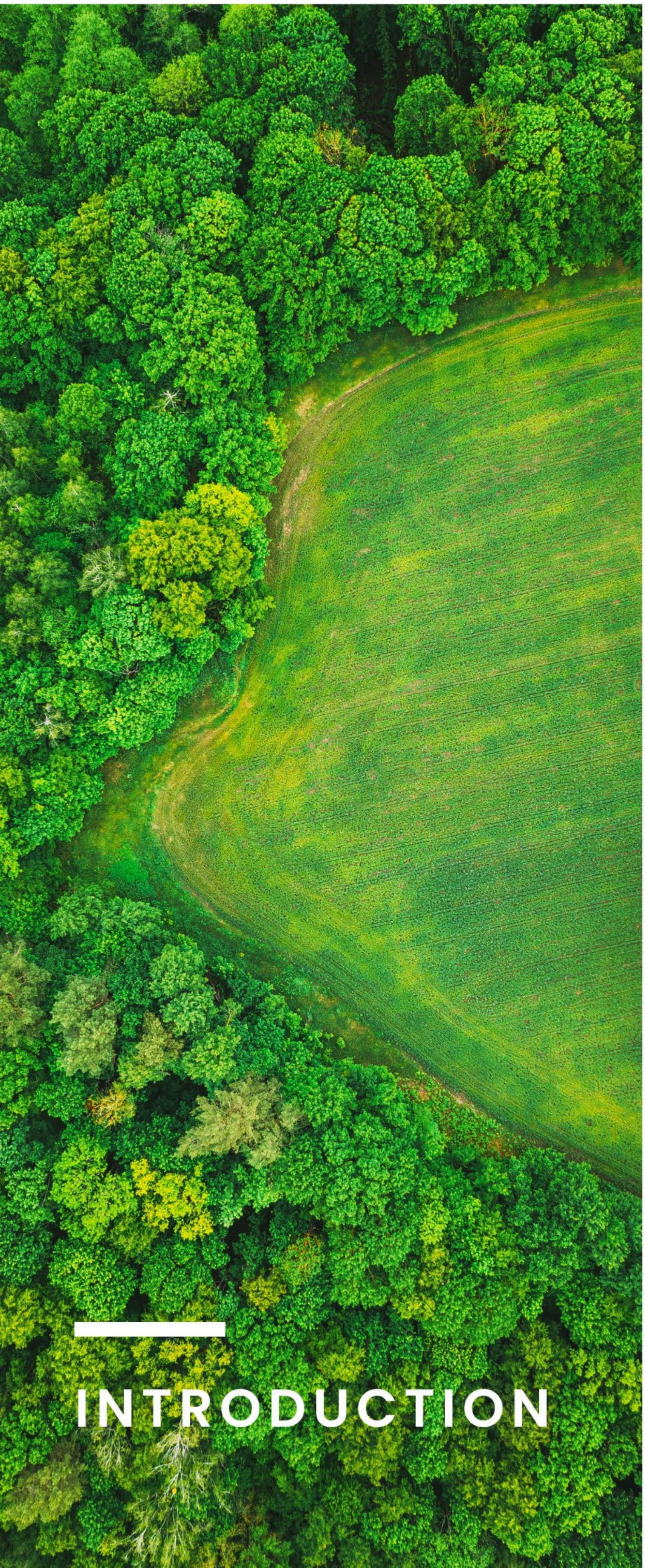

1 Introduction

This deliverable investigates the potential biomass sources which may be cultivated in marginal lands, hence unused, abandoned, contaminated or severely degraded areas, in Europe for biomethane production. Cultivating biomass on marginal lands addresses land-use challenges, such as food-feed-fuel competition, while preventing abandonment and preserving nature. Recovering degraded lands offers to biomethane producers the opportunity to increase carbon stock and to collect sustainable non-food feedstock. Moreover, adopting phytoremediation solutions helps to recover contaminated lands, which is a double opportunity to produce sustainable biomass and capture contaminants from soil.

However, competing claims and debates over the definition of such lands for biomass production still exist. Locating and quantifying their untapped biomass potential, together with the key issues to address from legislation, remain a challenge. Moreover, biomass supply potential, biogas productivity and system economics still remain an open issue, which today has been studied only at demo-scale. For instance, this deliverable refers to initiatives as EU projects (e.g. BIKE, S2Biom, MAGIC, PANACEA, SoilCare, GOLD, CERESIS, Phy4climate, BIO4A and BECOOL), technical studies and feedback from experts, policy makers and industry that provided an overview on the current scenario, including the state-of-the-art for agro-practices and land identification tools.

Lands characterization is fundamental issue to guarantee sustainable biomass supply, with no or low Indirect Land Use Change (ILUC), for the use as feedstock for biofuels, bioliquids, and/or biomass fuels production. The Renewable Energy Directive (EU) 2001/2018 (RED II), mandates the phase-out after 2023 of "high ILUC-risk" biofuels and introduces the option to certify "low ILUC-risk" biofuels, which are bioliquids and biomass based on feedstock that avoid displacement of food production (considering the principle of 'additionality'). According to the Annex IX part A of the RED II, low-ILUC-risk biomass can also be produced on certain types of marginal lands (i.e. severely degraded lands).

While several biowaste streams still remain untapped, even using them at their full potential would not be able to fulfil the biofuel targets on their own. Therefore, low-ILUC biomass production is needed to cover the gaps, but there are many issues that need to be considered which are also influenced by different policy instruments. These issues concern land availability and productivity, agronomic practices, and sustainability, particularly in relation to GHG emissions and carbon sinks, sustainable soils, biodiversity, water quality and quantity, rural and socioeconomic development.

All these aspects are influenced by existing and new regulations expected from *Common Agricutural Polic*y to the *EU Green Deal*, including the *Fit-for-55* package, the recast of the *Renewable Energy Directive* and the *Farm to Fork* Strategy. A key-role is played also by the *Sustainable Carbon Cycles*, focusing on both carbon farming and carbon removal certification. To achieve the *RePowerEU* target of biomethane set at 35 bcm by 2030, such policies and supporting mechanisms need harmonization to create synergies for common objectives. The scope of this deliverable is to review the existing definitions of marginal, suitable lands to produce low ILUC-risk biomass for biomethane production according to the current EU policy framework. Biophysical and economic opportunities for low ILUC-risk dedicated cropped biomass produced on lands with natural constraints are often applicable to unused, abandoned, and degraded lands.

Firstly, a review was made of the latest EU policy developments regarding low ILUC-risk biomass production, including climate and agro-related policies for marginal lands recovery. This review is based on a consultation of most recent publicly available policy documents, recent publications and outcomes from projects.

Secondly, an overview of the characteristics of unused, abandoned and degraded lands is made in terms of biophysical (soil and climate) characteristics, their potential extent and location and how they influence crop growth suitability. The presented information is mostly based on the information generated on this topic in MAGIC, BIKE and GOLD projects, and from a recent European Commission' contract study leaded by DG ENERGY.

Thirdly, an overview of biomass crops and their characteristics is discussed particularly in relation to their ability to grow under natural constraints. Here the report focuses on both annual and perennial crops, but particularly those that are not suitable to produce food or feed. For selecting crops, the deliverable builds on the knowledge generated mostly in the MAGIC project and follow-up publications and technical reports. The selection of crops to be used to produce low-ILUC biofuels is determined by:

- The technological readiness level (TRL) for 2030 while being adapted to European agroecological climatic zones.
- Suitability of feedstock for advanced biofuels.
- Good adaptability when cultivated in land with natural constraints.

Finally, recommendations according to BIP guidelines will be provided to support industry and policymakers to promote the biomethane sector using such feedstock sources both for the short- and long-term scenario.

2. European legislation

In this chapter the Renewable Energy Directive, Common Agricultural Policy and other Euopean strategies are described, together with national policies.

2 European legislation

Today biomethane production relies on biomass sources from crops either cultivated in agricultural areas (e.g., maize silage) or biowastes. To cover the large demand of biomass sources required by the RePowerEU [1], the use of biomass cultivated in marginal lands may play a crucial role. In the EU there is no legal definition for "marginal lands", even if this concept is often used in the context of EU agricultural, bioenergy, biochemicals, biomaterials and environmental policies. Generally marginal lands refer to areas either with limited agricultural productivity for economic issues [2], or where it is difficult to farm due to various factors such as poor soil quality, steep slopes, high susceptibility to erosion, contaminations of pollutants or low water availability.

Utilizing such lands for biomass supply can help avoid competition with food production and reduce the risk of ILUC (Indirect Land Use Change). The concept of "low ILUC-risk feedstock" is related to the EU 2001/2018 Renewable Energy Directive (also called RED II) [3], which is designed to promote the use of renewable energy sources and reduce greenhouse gas emissions in the EU-27. ILUC concept refers to the impact of biofuels and biomass production on land use patterns used for food and feed production, which indirectly move their production in other areas generating deforestation, greenhouse gas emissions, and biodiversity loss. To address this issue, RED II sets criteria and sustainability standards for biofuels and biomass production to ensure that they are produced in an environmentally responsible and sustainable manner. Feedstock sources that are expected to be “low ILUC” are typically: those that avoid competition with food production and other productive activities such as agricultural or forest residues and waste materials; crops that can be grown on lower quality land and are not suitable for feed and food; food crops grown with a low ILUC-risk certification.

RED II Implementing Regulation (EU) 2022/996 [4] on “rules to verify sustainability and greenhouse gas emissions saving criteria and low indirect land-use change-risk criteria” introduced definitions on unused, abandoned, and degraded lands that might be suitable for biomass production. However, definitions and implications may vary depending on the context and objectives of each legislative framework: in this case how Renewable Energy Directive (REDII) and the EU Green Deal targets are in competition with the Common Agricultural Policy (CAP).

2.1 Renewable Energy Directive

2.1.1 Scope and targets

The European Union (EU) has established a specific regulatory framework for the promotion of the production and use of renewable energy through the Renewable Energy Directive (EU) 2018/2001 (RED II) [3], which entered into force in 2018 and replaced the Renewable Energy Directive 2009/28/EC (RED) from 2009 [5]. Recently, RED II has been re-casted by the Directive EU 2023/2413 (RED III) [6], which updated the targets towards 2030.

Formerly, RED II has set the objective to achieve a share of at least 32% of energy from renewable sources in the Union's gross final consumption of energy by 2030. Biofuels counted towards the 32% renewable energy target and towards the transport target of minimum 14% of the energy used in the transport sector by 2030. The EU RED II encouraged the deployment of advanced biofuels, by limiting the quantity of biofuels produced from food and feed crops (starch-rich crops, sugar crops or oil crops) produced on agricultural land to max 7% of final consumption of energy in the road and rail transport sectors (the actual cap observed by a given Member

State will depend on the Member State). On the other hand, the overall target for the transport sector included a sub-target of 3.5% from advanced biofuels with intermediate targets of 0.2% in 2022 and 1% in 2025. Advanced biofuels were defined in RED II as biofuels that are produced from the feedstock listed in Part A of Annex IX. The biofuels produced from feedstocks listed in Part B of Annex IX (such as used cooking oil and animal fats) were also treated favourably, but their use was capped at 1.7% of transport energy demand in 2030 to avoid distortive effects on markets for by-products, wastes or residues.

In December 2019, the European Commission proposed the *European Green Deal* (EGD) [7] that set a vision of how to achieve sustainability and climate neutrality goals by 2050 to tackle climate and environmental challenges. Within this framework, sustainable alternative transport fuels remain an option to decarbonise the sectors in which electrification remains challenging. The *European Climate Law* [8] (i.e. the EGD translated into law) also set a legally binding target of net zero greenhouse gas emissions by 2050 and the intermediate target of reducing net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels. As part of the EGD, on 14 July 2021 the EC adopted the *Fit for 55* package [9], which provided updates of the existing climate and energy legislation to meet the EU objective of a minimum 55 % reduction in greenhouse gas (GHG) emissions by 2030. A key element of this *Fit for 55* framework was the revision of the RED II (i.e. RED III). Furthermore, on May 2022, the Commission proposed in the *REPowerEU* plan [1] to further raise this RES target to a 45% share by 2030.

Finally, today the RED II' recast (RED III) sets the EU's overall energy consumption to 42.5% by 2030, with an additional 2.5% indicative top up to allow the target of 45% to be achieved [6]. The RED III has increased the ambition level for the use of renewable fuels and renewable electricity in transport, where Member States have the possibility to choose between: either a binding target of 14.5% reduction of greenhouse gas intensity in transport from the use of renewables by 2030; or a binding share of at least 29% of renewables within the final consumption of energy in the transport sector by 2030. The Directive also set a binding combined sub-target of 5.5% for advanced biofuels (generally derived from non-food-based feedstocks) and renewable fuels of non-biological origin (mostly renewable hydrogen and hydrogen-based synthetic fuels) in the share of renewable energies supplied to the transport sector. Within this target, there is a minimum requirement of 1% of renewable fuels of non-biological origin (RFNBOs) in the share of renewable energies supplied to the transport sector in 2030.

Advanced biofuels can also contribute to the targets imposed by the ReFuelEU Aviation [10] [11] and FuelEU Maritime [12] regulations. ReFuelEU Aviation aims at promoting sustainable aviation fuels through a blending mandate for fossil suppliers to reach an increasingly high level of sustainable aviation fuels into jet fuel (2% by 2025, 6% by 2030 and 70% by 2050) and promoting the uptake of synthetic fuels (0.7% by 2030 and 28% by 2050). The Regulation 2023/1805 focuses on the use of renewable and low-carbon fuels in maritime transport: it sets a limit on the GHG content of the energy use in ships decreasing over time compared to the fleet average in 2020 reduced by 2 % from 2025, 6% from 2030 and 80% from 2050. Within this regulation, liquid biofuels, biomethane, renewable fuels of non-biological origin and recycled carbon fuels are taken into account. Non–compliant new fuels and food/feed biofuels are considered to have the same emission factors as the least favourable fossil fuel pathway. These initiatives have been proposed by the European Commission as part of the Fit for 55 package to decarbonize the aviation and maritime sectors.

2.1.2 Sustainability criteria

Directive 2009/28/EC [3] introduced a set of sustainability criteria for biofuels, including criteria protecting land with high biodiversity value and land with high-carbon stock. The RED II defined reinforced EU sustainability criteria for biofuels used in transport as well as for solid and gaseous biomass fuels for heat and power to deliver high greenhouse gas emission savings, do not cause deforestation or degradation of highly biodiverse habitats and that forest harvesting minimises biodiversity impact, while promoting efficient use.

Biofuels shall not be produced from raw materials originating from high biodiversity land (primary forests; areas designated for nature protection or for the protection of rare and endangered ecosystems or species; and highly biodiverse grasslands); high carbon stock land (wetlands, continuously forested land or other forested areas); or peatland (as of January 2008). A new sustainability set of criteria for forest biomass sources, to ensure that biomass meets the defined land-use, land-use change and forestry (LULUCF) regulation (updated in 2023 [13]), are now adopted. The changes in carbon stock associated with biomass harvest are accounted towards the country's commitment to reduce (or limit) greenhouse gas emissions (hence LULUCF-sector emissions should maintain specific carbon removal levels).

Biofuels, bioliquids and biomass fuels produced from biogenic feedstocks, wastes and residues, are required to fulfil only the greenhouse gas emissions saving criteria. In order to determine the categories of feedstock that may contribute to the climate targets, the RED II identifies low ILUC-risk biofuels through the Implementing Regulation (EU) 2022/996 [4], while the Delegated Regulation (EU) 2019/807 [14] defines high ILUC-risk fuels and sets out criteria for the certification of low ILUC-risk fuels that should be exempt from the specific and gradually decreasing limit for food and fed based biofuels.

Finally, Member States shall ensure that biofuels and bioenergy produced in a way that minimises undue distortive effects on the biomass raw material market and harmful impacts on biodiversity.

2.1.3 GHG emissions calculations

In the European Union, the methodology for calculating GHG emissions from biofuels and bioenergy is set out in the RED II [3] and consists in rules for calculating their carbon intensity from production to transportation and use. Emissions of CO_2 from the combustion and conversion of biofuels are not accounted in the final carbon intensity because of biogenic origin. The methodology takes into account other CO_2 equivalent emissions such as CH_4 (e.g. from biogas fugitive emissions) and N_2O (e.g. from fertilizers), and the accounting system considers how much emissions are saved by using biofuels instead of fossil fuels. The GHG emissions savings are calculated by comparing them to the carbon intensity of a reference fossil-based fuel set at 94 gCO2e/MJ., 183 g CO_2eq/MJ for electricity production, for the production of heating and/or cooling 80 g CO_2eq/MJ. Savings are expressed as a percentage and are required to pass a GHG reduction threshold to be considered eligible: these requirements are 50-65% for biofuels, depending on the date of facility construction, and 70% for RFNBOs and Recycled Carbon Fuels (RCFs). At the latest from 2030 biomass energy for electricity, heating and cooling production must fulfil the threshold of 80% reduction [7]. In order to support the market operators with the GHG emission assessment, the RED II contains a list of pre-calculated "default" values for liquid biofuels (Annex V) and bioenergy (Annex VI) conversion pathways as regards their carbon intensity and emissions savings. Such Annexes also contains details to perform GHG emission accounting to calculate real values. Then, to certify their products, operators can use voluntary schemes and national certification schemes available for EU countries [15], which help to ensure that biofuels, bioliquids and biomass fuels are sustainably produced by verifying that they comply with the EU sustainability criteria. For biomethane production, the operators should deliver their GHG emissions calculations when their production is above 200 m^3 per hour of methane (as depicted in the RED III).

2.1.4 Advanced biofuels requirements and ILUC

While biofuels are important in helping the EU meet its greenhouse gas reduction targets, generally their production comes from croplands that are also used (or also were previously used) for feed and food production. An increase in the demand of crops for biofuel production impacts on the other markets through price-mechanisms which both raise yields and extension of the crop area to respond to the increased demand.

The increased demand for biofuel can be filled partly by the expansion of agricultural land into non-crop land, possibly into areas with high carbon stock, such as forests, wetlands, and peatlands. This process is known as indirect land use change (ILUC). To address the issue, high ILUC-risk biofuels have been limited (or banned in some cases) and biofuels, bioliquids and biomass fuels in EU shall be certified as low ILUC-risk. The contribution of high ILUC-risk biofuels will be limited at 2019 levels, and then gradually reduced to zero by 2030 at the latest. In 2019 the European Commission published a report on the status of production expansion of relevant food and feed crops worldwide [16]. The Delegated Regulation EU 2019/807 on indirect land-use change [14] set down provisions to determine the high ILUC-risk feedstock for which a significant expansion of the production area into land with high carbon stock is observed. It also set out criteria to certify low ILUC-risk biofuels, bioliquids and biomass fuels.

Furthermore, specific rules and methodological guidance for certification of low ILUC-risk biofuels, bioliquids and biomass fuels have been included in the Implementing Regulation 2022/296 on sustainability certification proposed by the Commission in line with Article 30(8) of the RED II, and adopted on 14th June 2022 [4]. In order to translate part of these policies into practical information for the operators producing advanced biofuels, in December 2022 the Commission released the draft Delegated Directive for the amending Annex IX (RED II) list for eligible feedstocks for the production of biogas for transport and advanced biofuels [17]. This list is subject to periodic review by the European Commission, following an analysis of the potential feedstock following: the principles of the circular economy and of the waste hierarchy and avoiding significant distortive effects on markets, negative impacts on the environment and biodiversity and avoiding creating an additional demand for land. Final adoption of the revised list is highly likely to be done at any time during the first half of 2024, followed by an 18-month transposition period for Member States.

2.2 Common Agricultural Policy

The Common Agricultural Policy (CAP) is a policy framework established by the European Union (EU) to support and regulate agriculture in its Member States [18]. It was originally implemented in 1962 and has undergone several reforms since then. The primary goals of the CAP are to ensure food security, promote sustainable agricultural production, support rural development, and stabilize agricultural markets. On 2nd December 2021, the agreement on reform of the common agricultural policy (CAP) was formally adopted. The new legislation, which entered into force on 1 January 2023, paves the way for a fairer, greener and more performance-based CAP. It seeks to ensure a sustainable future for European farmers, provide more targeted support to smaller farms, and allow greater flexibility for EU countries to adapt measures to local conditions.

The CAP 2023-2027 introduces mandatory eco-schemes for MSs aimed at rewarding farmers who adopt environmentally friendly practices. The new legislation may offer several opportunities to incentivize low ILUC-risk biomass production in EU areas (as described in 4.2). However, it is noteworthy that as regards the CAP, there is no link between the direct support provided and (the use of crops for) biofuel production.

This is embodied in the objectives aligned with the current environmental and climate legislation. Incentivizing the cultivation of crops on unused, abandoned, or severely degraded land offers the opportunity to restore low quality land; this builds not only on existing farm income support, support to Areas facing Natural or other specific Constraints (ANCs) and greening payment measures, but also more general rural development funding regulation. The CAP is also structured to be flexible to the needs and conditions of the different EU Member States and regions: national governments can design their Strategic Plans (for the new CAP) to exploit the alignment between their own environmental objectives and the low ILUC-risk system (alongside other residual based biofuel pathways), while also introducing additional sustainability requirements on crop-based biofuels preferably creating win-wins on both farm income and wider environmental sustainability.

Producing specific, mostly perennial crops on agricultural lands with many natural constraints (ANC-classified lands) can intersect with other goals on soil health, carbon sequestration, and runoff control through improving ground cover. Low ILUC-risk production systems may therefore benefit directly or indirectly from provisions in the EU's Farm to Fork Strategy, Nitrates Directive, Pesticides Regulation, Habitats Directive, and Biodiversity Strategy, among others. A recent overview of the CAP instruments that may help incentivize Low ILUC-risk biomass production is provided in BIKE Deliverable 2.2 [19].

2.3 Biodiversity: Soil and Forest strategies

The EU Soil Strategy [20] is a component of the broader EU Biodiversity Strategy [21], which aims to address the decline in biodiversity and promote the sustainable use of natural resources within the European Union. In line with the European Green Deal [7], EU soil strategy for 2030 sets out a framework and concrete measures to protect and restore soils, and ensure that they are used sustainably. It sets a vision and objectives to achieve healthy soils by 2050, with concrete actions by 2030. The new proposal for the Soil Health Law [22] states:

"Scientific evidence indicates that about 60 to 70% of soils in the EU are currently in an unhealthy state. All Member States are facing the problem of soil degradation. Degradation processes are continuing and worsening. The drivers and impacts of the problem go beyond country borders, reducing the soil's capacity to provide these vital services throughout the EU and neighbouring countries. This creates risks for human health, the environment, climate, economy and society, including risks for food security, water quality, increased impacts from flooding and droughts, biomass production, carbon emissions and a loss of biodiversity."

Therefore, the aim is to create the conditions for action to manage soils sustainably and to tackle the costs of soil degradation. Healthy soils are essential for achieving climate neutrality, a clean and circular economy and halting desertification and land degradation [23]. They are also essential to reverse biodiversity loss, provide healthy food and safeguard human health. When sustainable soil restoration practices are considered within low ILUC-risk biofuels production (remaining aligned with the most recent EU policies), Panoutsou et al [24] showed several case studies that demonstrated that degraded lands recovery offered opportunities not only for farmers and biofuels producers, but also to promote biodiversity and climate targets.

It is also worth to mention the new EU forest strategy for 2030 [25] which is one of the flagship initiatives of the European Green Deal and builds on the EU biodiversity strategy for 2030. The pillars of this initiative are protecting, re-afforesting and promoting sustainable practices to strengthen the role of forests as natural areas and carbon sinks. Recovery of degraded areas to restore forests is something that may be in competition with biofuels production as depicted in the LULUCF regulation [13], described in section 2.1.2.

2.4 Carbon farming within Sustainable Carbon Cycles

The land sector is key for reaching a climate-neutral economy since can capture and store CO_2 from the atmosphere. However, in order to encourage agriculture and forestry sectors to deliver climate actions and contribute to the European Green Deal, it is necessary to create direct incentives for the adoption of climate-friendly practices. Currently there is no targeted policy tool to significantly support the increase and protection of carbon sinks for land managers. For this reason, in December 2021 the Commission adopted the Communication on Sustainable Carbon Cycles [26], as announced in the Farm to Fork Strategy [27]. The Communication sets out short- to medium-term actions aiming to address current challenges to carbon farming in order to upscale this green business model that rewards land managers for taking up practices leading to carbon sequestration, combined with strong benefits on biodiversity.

These include:

- promoting carbon farming practices under the CAP and other EU programmes such as LIFE and Horizon Europe, in particular under the Mission "A Soil Deal for Europe", and under public national financing;
- driving forward the standardisation of monitoring, reporting and verification methodologies to provide a clear and reliable framework for carbon farming;
- providing improved knowledge, data management and tailored advisory services to land managers.

Examples of effective sustainable carbon cycles promoting carbon farming practices include:

- Afforestation and reforestation that respect ecological principles favourable to biodiversity and enhanced sustainable forest management, including biodiversity-friendly practices and adaptation of forests to climate change.
- Agroforestry and other forms of mixed farming combining woody vegetation (trees or shrubs) with crop and/or animal production systems on the same land.
- Use of catch crops, cover crops, conservation tillage and increasing landscape features: protecting soils, reducing soil loss by erosion, and enhancing soil organic carbon on degraded arable land.
- Targeted conversion of cropland to fallow or of set-aside areas to permanent grassland.

- Restoration of peatlands and wetlands that reduces oxidation of the existing carbon stock and increases the potential for carbon sequestration.

The Commission has already promoted carbon farming in its recommendations on the Member States' CAP Strategic Plans [28] and will continue outlining carbon farming possibilities in its further assessment of the CAP targets.

In addition, in order to provide clarity on the quality of carbon removals and address the current lack of standardisation of existing frameworks, in 2022 the Commission introduced a legislative proposal to develop a regulatory framework for certifying carbon removals [29] based on robust and transparent carbon accounting to monitor and verify their authenticity. Within this initiative, bioenergy with carbon capture and storage (BECCS) technologies and other nature-based solutions for carbon sequestration (e.g. biochar) can be certified to be coupled with biofuels and bioenergy production creating new business models for farmers and foresters.

2.5 National policies

Rural development was strongly influenced by the administrative and institutional framework in each country. A part of decisional power is leaved to Member States (MS), which define strategies to preserve biodiversity and foster agriculture in their national territories. Decentralised management increases the effectiveness of development policies by bringing supporting schemes closer to the needs and priorities expressed by local communities, but also may introduce different interpretations of lands definition and use. For instance, with lack of clarity between RED, CAP and national policies, some marginal lands under degradation may be classified as temporary grassland or equivalent for landowners to receive subsidies. Therefore, specific national and regional regulation should be further developed in cascade to the recent EU policies the time that marginal lands are considered for biomass production.

3. Definitions of land

In this chapter different definitions of land are described, such as utilised agricultural area, marginal lands, unused, abandoned and degraded land, and contaminated lands.

3 Definitions of land

3.1 Utilized Agricultural Area

In the last decades the agricultural sector passed two diverging trends in the use of agricultural lands: (1) intensification and specialisation on land with greater production potential; (2) abandonment and degradation of more economically marginal land. Therefore, lands outside the Non-Utilized Agricultural Area (N-UAA) include the category of abandoned, degraded and contaminated areas.

To identify abandoned farmland through changes in UAA over time, it is necessary first to determine how UAA and other agricultural land use classes are officially defined in statistics. It is also necessary to understand how these definitions translate in EU-wide and national datasets and how these datasets also relate to data determining the agricultural areas eligible for support under the Common Agricultural Policy (CAP).

Member States have their tools (Integrated Administration and Control System, IACS [30]) to monitor land use and report data to Eurostat on total farm area (FA), agricultural area (AA), and UAA through the Farm Structural Survey (FSS). UAA is the smallest of these areas, defined as 'the total area taken up by arable land, permanent grassland, permanent crops and kitchen gardens used by the holding, regardless of the type of tenure or of whether it is used as a part of common land'. For specific definitions, the report commissioned by DG Energy in 2022 "Analysis of actual land availability in the EU; trends in unused, abandoned and degraded (non-)agricultural land and use for energy and other non-food crops" [31] provides more information.

The Member States with the largest differences between UAA and determined area are generally countries characterised by many very small (and often marginal) farms. E.g. in 2019, 57.9% of UAA in the EU-27 was designated as areas with natural or other area-specific constraints (ANC), ranging from 2.5% in Denmark to 100% in Luxembourg and Malta [19].

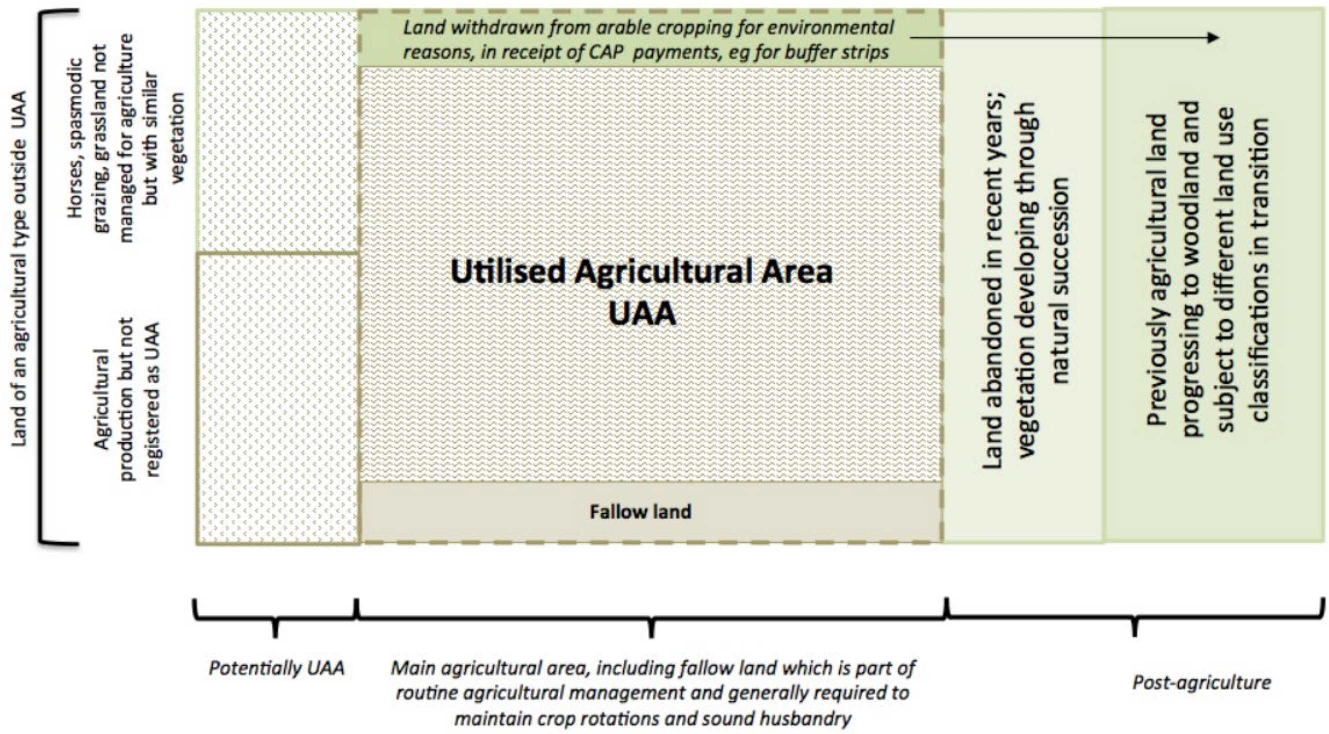

FIGURE 1 USE OF AGRICULTURAL AREA AND TRANSITIONS[29]

3.2 Marginal lands

In EU there isn't a clear definition for marginal lands, since it generally refers to areas of land that are considered less productive or less suitable for traditional agricultural or economic activities compared to more fertile or productive lands. These lands often have limitations or challenges that make them less desirable for conventional land use [32]. To evaluate the farming potential of a certain type of lands, JRC guidelines [33] identified biophysical limitations as: adverse climate, excessive wetness, low soil fertility, adverse chemical conditions, poor rooting conditions and adverse terrain conditions. Marginal lands are defined well as Area of Natural Constraints (ANCs) and also mapped relatively well (in EU) thanks to numerous projects (as described in the next chapters). EU H2020 MAGIC project deliverable 2.2 [34] provided a full review of all definitions that have been used in literature for "marginal lands" from 1817 to today.

3.3 Unused, abandoned and degraded land

One of the options to produce low ILUC-risk biomass is through growing non-edible crops in non-UAA areas, hence in unused, abandoned, and degraded lands as has already been envisaged in the RED II. Following the Delegated Act [14] of the RED II on ILUC-risk biomass, there are three types of lands defined as follows:

1. Unused lands: 'unused land' means areas which, for a consecutive period of at least 5 years before the start of cultivation of the feedstock used for the production of biofuels, bioliquids and biomass fuels, were neither used for the cultivation of food and feed crops, other energy crops nor any substantial amount of fodder for grazing animals.
2. 'Abandoned land' means unused land, which was used in the past for the cultivation of food and feed crops but where the cultivation of food and feed crops was stopped due to biophysical or socioeconomic constraints.
3. 'Severely degraded lands' means 'land that for a significant period of time has either been significantly salinized or presented significantly low organic matter content and/or has been severely eroded'.

According to the DG-Ener study [31], data on unused, abandoned or degraded lands (as defined in the RED II) are practically not available in EU-wide data sources, nor in national or regional data. The main reason for not registering land that goes out of production and becomes abandoned or degraded is because it then also loses agricultural land status and is therefore no longer registered in agricultural statistics. This is confirmed by the fact that the only unused land categories for which data are collected refer to lands that are temporarily out of use, such as fallow land or unused lands. However, if they lands are unused for a couple of years, it is a sufficient timeframe to lose agricultural status and registration.

These categories can also overlap with marginal land and/or in lands with natural constraints. Mapping exercises of marginal lands with low ILUC in the EU has been much advanced in recent years in several EU projects (see next chapters), mostly involving the identification according to biophysical constraints. In spite of this, much progress is still to be made to map such areas in a reliable way to support the understanding of their extent, location and physical, technical and socio-economic potential to produce low ILUC-risk biomass in the future.

3.4 Contaminated lands

Contaminated lands are generally defined as a site where pollutants or hazardous substances are present in the soil, surface water, or groundwater at levels that pose a risk to human health or the environment. The EU has developed guidelines and regulations to address contaminated land through its environmental policies. The main legal framework for contaminated land in the EU is the Industrial Emissions Directive (2010/75/EU) [35], which sets out provisions for the prevention and control of pollution from industrial activities. The directive includes requirements for the identification and remediation of contaminated sites. Additionally, individual EU member states may have their own national legislation and regulations regarding contaminated areas, which may vary to some extent.

These national regulations often consider the EU framework but can include additional measures specific to the country's environmental and health concerns. The process for defining and identifying contaminated land typically involves assessments and investigations conducted by competent authorities. These authorities may use various criteria and guidelines, such as soil quality standards and risk assessment methodologies, to determine the presence and extent of contamination. Once a site is identified as contaminated, the responsible party or landowner is generally required to take appropriate remedial measures to clean up the site and mitigate the risks associated with the contamination. Remediation can involve a range of techniques, such as soil excavation, containment, treatment, or monitoring, depending on the nature and extent of the contamination.

It's important to note that specific definitions and procedures related to contaminated land can vary across different EU member states, as they have some flexibility in implementing EU directives and regulations. Therefore, for detailed and up-to-date information on the definition and management of contaminated land in a particular EU country, it's advisable to refer to the national environmental authorities or legislation of that country. EC JRC provided a report including the current state of knowledge on the management of contaminated sites in Europe [36] and then improve the text including feedback from stakeholders and experts [37].

4. Opportunities and barriers

This chapter discusses challenges such as land availability, biomass productivity, agronomic practices, soil requirements and sustainability issues, particularly in relation to GHG emissions and carbon sinks.

4 Opportunities and barriers

4.1 Crops for biofuels

Sustainable biofuels are an important tool for the decarbonization of transports, in particular for hard-to-abate sectors as aviation, maritime, and heavy-duty vehicles with limited short-term alternatives for fuel supply. Furthermore, biomethane may be also used to replace methane into the natural gas grid, contributing to green industry, transports, agro-machineries and residential heating without changing the current infrastructures. In order to deliver the 35 bcm biomethane target of the REPowerEU, a huge demand of sustainable bio-feedstock is needed and cannot rely only on wastes and residues. For this reason, Task Force 3 of the BIP aims at providing sustainable alternatives for biomass supply. Recently IFEU [38] reviewed several studies reporting the biomethane potential at 2030 in EU differentiated per feedstock source, and showed how the contribution of crops cannot be neglected. This chapter analyses the implications in using biomass derived from non-conventional cropping system for biogas production.

4.1.1 Intermediate crops

The RED II allows the production of biofuels produced from food and feed crops grown as intermediate crops, which are crops other than the main crop, "provided that the use of such intermediate crops does not trigger demand for additional land" (RED II, Article 2, point 40). However, Annex IX' revision (see 2.1.2) may introduce further definitions which can add some feedstock sub-categories in Annex IX Part B, with the cap fixed at 1.7% – although this cap is subject to adjustment by Member States if supported by feedstock availability.

Intermediate crops offer a huge opportunity for biomass supply when produced with sustainable practices which are not in competition with food and feed production (see BIP deliverable 3.1 on "Biomethane potential from novel cropping systems").

Moreover, Nitrates Directive [39] empowers Member States to recognise the use of crop rotations, cover crops and perennial crops in their codes of good agricultural practice, therefore additional biomass not suitable for food and feed purposes may be available without lowering the main crop yield. For instance, some initiatives such as BiogasDoneRight [40], already showed benefits for both biofuel and food crops cultivated in a common agro-system. Additionality and sustainability (intended as Soil Organic Content (SOC) increase, lower fertilizers input, etc.) are key aspects that are needed to emphasize the role of intermediate cropping systems for biofuels production. However, there is still no definition of which practices would be promoted to offer such opportunities, since certification mechanisms may have different interpretation depending on the supply chain under investigation.

Another challenge arises in defining the connection between low ILUC-risk certification and food and feed crops. These crops are categorized based on 'agricultural land,' a term lacking formal definition. This prompts the query of whether degraded or unused land could be considered non-agricultural. If low-productivity land is deemed non-agricultural, crops grown on such land via a low ILUC-risk project might not meet the criteria for food and feed crops under the RED' definition, thus losing eligibility for low ILUC-risk certification.

Conversely, if all land where agricultural crops grow, even if of poor quality, is deemed agricultural land, the reference to agricultural land in defining food and feed crops becomes redundant. To resolve this ambiguity, a straightforward solution could involve allowing low ILUC-risk certification for all crops or amending the definition of food and feed crops by removing the specification of "on agricultural land" [41].

4.1.2 Biomass from severely degraded lands

The “severely degraded lands” (still part A into the REDII Annex IX’ revision) may offer a new opportunity to grow sustainable biomass for biomethane without any limit due to the legislation.

Today, the RED II already provides a bonus of 29 g CO2eq/MJ for those biofuels cultivated in “restored” severely degraded land (RED II, Annex VI part C point (8)). Such emission credit is attributed if evidence is provided that the land:

a) was not in use for agriculture or any other activity in January 2008.
b) is severely degraded land, including such land that was formerly in agricultural use. The bonus of 29 g CO2eq/MJ shall apply for a period of up to 20 years from the date of conversion of the land to agricultural use, provided that a steady increase in carbon stocks as well as a sizable reduction in erosion phenomena for land falling under (b) are ensured.

However, there are still limiting factors for potential biomass sources cultivated in these areas, since they may be limited from National-specific legislations or specific high biodiversity classification (e.g. wetlands, peatlands, or forest) which could not recognize such feedstock as biomass cultivated in degraded lands as low ILUC-risk feedstock (see details in the deliverable 5.1 of the H2020 project BIKE [42]).

4.1.3 Concept of low ILUC-risk feedstock (RED II)

Biofuels from 'low ILUC-risk' feedstock shall meet the following criterion to be certified as eligible towards the REDII’ targets:

1. Adherence to sustainability and GHG criteria as stipulated in Article 29 of the RED II for biofuels and biomass fuels.
2. Utilization of additional feedstock obtained from measures enhancing crop productivity or cultivation from either previously unused agricultural lands, or seriously degraded lands.
3. Substantial evidence validating compliance with the aforementioned criteria, including details about the measures implemented to boost feedstock production, the specific areas where these measures were implemented, and the average yield over a three-year period from these lands.

From a recent analysis performed by H2020 BIKE project [41], one category that is currently excluded from low ILUC-risk certification under the RED II rules is the one consisting in “non-food lignocellulosic crops”. The experts noted that it would be theoretically possible to apply the certification methodology to projects cultivating lignocellulosic (energy) crops which are suitable for the reclamation of abandoned, degraded (or under degradation) and unproductive lands for food and feed crops. However, being still classified as “agricultural lands” under the UAA, non-food biomass from such lands cannot be easily certified for advanced biofuels or biogas for transport production, even if the categories “non-food cellulosic crops” and “other lignocellulosic material” present in the RED II’ Annex IX potentially include such biomass sources.

A supporting tool that may facilitate this procedure is the calculation of ILUC emissions. While the RED II assigns zero GHG emissions attributed to the ILUC value for a specific political decision, the use of certain biomass may generate negative emissions (i.e. carbon sequestration). For instance, perennial energy crops (using GLOBIOM) may generate even negative ILUC factor [43], while other annual crops (e.g. switchgrass) may lead to a positive ILUC impact. The study of Sumfleth et al (2020) [44] reported some examples of ILUC emissions confronting conventional to advanced (lignocellulosic-based) biofuels. However, since low ILUC-risk certification for biomass supply does not still rely on GHG emissions calculations, the EC should provide additional guidelines on which are the energy crops and the best available practices that may be an attractive option to produce sustainable biofuels (see next chapters for some examples).

4.1.4 Potential frauds for the certification process

It is worth noting that a recent assessment focused on feedstocks to produce advanced biofuels performed by experts for DG ENERGY [45], highlighted that crops grown on degraded lands produce biomass that may be at high risk of frauds, while biomass from contaminated lands has been assessed at medium risk. This because it results difficult to distinguish biomass cultivated from degraded land vs traditional biomass, which results in the same biofuel conversion yield. The issue regards biomass from contaminated lands, where pollutants may not carry over into fuels made from feedstock grown on polluted land (biogas, ethanol, biodiesel, etc.). Therefore, it is likely that it will be difficult to distinguish fuels derived from feedstock produced on polluted land from other fuels produced on non-polluted land. Moreover, definition of degraded or polluted lands will differ between countries and classifying land as degraded or polluted may be attractive if inclusion in Annex IX and associated benefits depend on that classification.

4.2 Common Agricultural Policy

Agriculture and rural areas are central to the European Green Deal, and the CAP 2023-27 will be a key tool in reaching the ambitions of the Farm-to-Fork and Biodiversity strategies. As regards biofuels, considering the current scenario of EU biomass supply, feedstock production still relies on food and feed crops cultivated in agricultural areas [46]. Abundant crops production for food (e.g. maize), coupled with incentives deriving for 1st generation biofuels or biogas production, are still the only “stable” business models for farmers producing biomass supply.

Non-food and feed biomass production (i.e. low ILUC-risk projects) are not direct targets of the CAP. It is noteworthy that as regards the CAP, there is no link between the direct support provided and (the use of crops for) biofuel production. However, they may have a range of characteristics that could make them eligible to be supported in post-2023 CAP such as: to prevent the abandonment of land facing ‘natural or other specific constraints’ to farming, i.e. unused or abandoned lands; to promote Farm to Fork strategy identifying carbon farming as a priority for regulatory action (see next paragraph); to propose new cropping system in areas recovered by enhancing soil carbon sequestration through low ILUC-risk projects, for example by the application of digestate or biochar. Some examples of sustainable crops for farmers are reported in the Briefing Note #10 of BIKE project [47].

The need of integrating food security with agro-models supporting climate, soil and biodiversity preservation promoted by biofuels production is of primary importance. According to the most recent edition of the JRC MARS Bulletin crop monitoring in Europe [48], Eastern EU showed a downward revision of the yield forecasts for grain maize (-2%) and sunflowers (-5%) and a slight upward revision for other summer crops. The reasons are attributed to climate change, which is impacting Europe with longer warm seasons, but even greater drought period.

Since CAP can also support measures to preserve lands exposed to extreme conditions (from desertification to longer water accumulation or extreme weather events), the promotion of sustainable practices based on low ILUC-risk feedstock is a real opportunity [49]. As suggested by FAO [50], alternating biofuels and food/feed production applying good agricultural practices is possible. Bioenergy can bring new investment into the agricultural sector for new employment opportunities, modernized infrastructures, and market access in rural areas.

	EU	National
Maintaining land under agriculture production	Common Agriculture Policy (CAP) • Pillar 1 Direct support & market measures from EU (agri-environmental schemes) • Pillar 2 Direct payments co-financed by MS	• Legislation to maintain agriculture land in active production use • Legislation addressing farm structure and land tenure issues
Bringing land back into active use; and stimulating biomass cropping for energy and other non-food purposes	Structural Funds • RED II	• Financial instruments: land taxes or preferential rates for loans. • Land use, development control, zoning policies
	Green Deal CAP Forest Strategy Soil Strategy	National Energy and Climate Plans National CAP strategic plans

FIGURE 2 EU AND NATIONAL POLICIES INFLUENCING ON LAND USE AND BIOMASS

4.3 Carbon farming

Carbon crediting in EU is regulated by the Emission Trading System (EU ETS) [51], which is the world's first "cap and trade" carbon market including power sector, large industries, shipping and intra-EU flights. Emissions from agriculture and other specific sectors (e.g. fisheries, forests) are outside the scope of the EU ETS since they are covered by the Effort Sharing Regulation (ESR) [52]. The ESR sets binding targets for Member States (from 0% to 40% GHG emissions reduction by 2030 compared to 2005 levels), reflecting the relative wealth of Member States, and they are meant to collectively deliver 30% emissions reduction by 2030, with a proposal for a net zero target by 2035 [53]. Agricultural CO2 emissions (or removals) linked to changes in carbon stored in soils and biomass due to cropland and grassland management practices are on the other hand covered by the Land use, land use change and forestry (LULUCF) Regulation [13].

The Regulation sets a "no-debit" rule, requiring Member States to ensure that accounted emissions (debits) from all land-use categories within the LULUCF sector are less than accounted removals (credits) in the period of 2021 - 2030. Therefore, ESR and LULUCF don't provide direct incentives, and GHG emissions certificates (e.g. from carbon farming or other agro- or forest-activities) cannot be traded on the ETS carbon market. Therefore, the European Commission is proposing a new mechanism to reward farmers for implementing carbon farming measures through the Carbon Removals' initiative and Member States have the option to provide remuneration for these efforts through public funding or private, voluntary carbon markets.

Environmental campaigners raised concerns that the regulation might allow farmers to declare emission reductions as carbon farming and negative emissions, potentially leading to extra financial benefits for the agriculture sector instead of imposing additional costs through the ETS, as other sectors face.

However, properly addressing crop systems and certifying methodologies (e.g., from Carbon Removals' initiative), it is possible to develop new opportunities to foster the carbon market uptake in the coming years.

Energy policies Green Deal, RED II, RePowerEU	**CAP**	**Farm-to-Fork and Climate Targets**	**Biodiversity**
• Biomass supply to achieve the mandate for advanced biofuels production (no food/feed competition) • Contributing to achieve 35 bcm biomethane target with sustainable feedstock • Contributing to reduce GHG emissions using low ILUC-risk feedstock • GHG emissions crediting system for marginal lands recovery and soil organic carbon increase	• Recovering lands for agriculture • Promoting new soil restoration techniques using catch-, cover-, inter-cropping • Using digestate to recover degraded soil and to reduce synthetic fertilizers • New business models for farmers based on biomethane/biochemicals and food & feed production • Food security	• Promoting carbon farming according to the sustainable carbon cycles target • Protecting soils, reducing soil loss by erosion, and enhancing soil organic carbon on degraded arable land • Biological carbon capture opportunities	• Recovering degraded soils • Recovering lands/areas to restore biodiversity (reafforesting, restoring native plants, …) • Contributing to carbon sequestration • Restoration of contaminated areas • Restoration of peatlands and wetlands reducing oxidation of existing carbon stock

FIGURE 3 THE KEY POLICIES INFLUENCING ON LAND USE AND BIOMASS PRODUCTION

5.

Mapping exercises for marginal lands

This chapter describes existing mapping exercises to identify land type, location, and areas for marginal lands, and existing EU and national projects.

5 Mapping exercises to identify land type, location, and areas for marginal lands.

5.1 Existing mapping exercises

During the last 10-15 years, several mapping exercises across EU (both funded by EU project or national initiatives) provided GIS maps on marginal lands, creating different layers as regards soil type, climatic regions, crops history and other parameters. The most recent and updated model has been developed within the EU project MAGIC (described in the next section) which identified the marginal lands in Europe suitable for energy crops cultivation with assessed their potential yield [54].

The methodology is based on spatial explicit assessment and the identification of Marginal Agro-Ecological Zonation (M-AEZ). When mapping marginal lands, multifactor constrains have been considered as biophysical, land management, socio-economic constraints and ecosystem services and threats have been considered as shown in Figure 4.

According to the proposed modelling system and also considering the potential lands overlapping, MAGIC mapped 694,395 km² of marginal lands in EU, equal to 29% of the total agricultural area (2,391,152 km²). The most common factors defining marginal lands are due to rooting limitations, i.e. 12% of the agricultural area. This is followed by adverse climate and excessive soil moisture conditions, occurring respectively for 11% and 8%. The study for DG ENERGY of Elbersen et al (2020) [31] relies on MAGIC outcomes

Biological constraints used for mapping marginal land

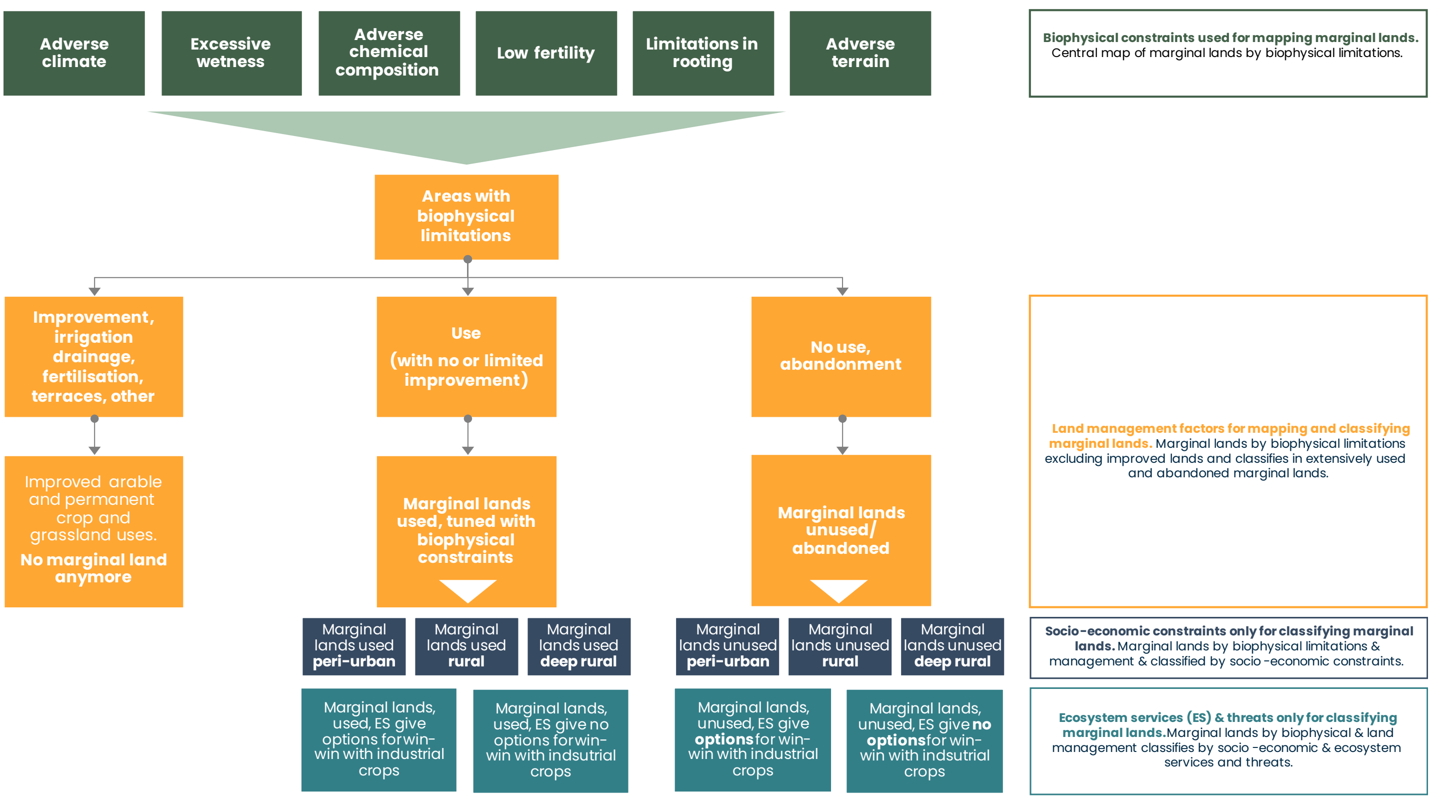

FIGURE 4 METHODOLOGY TO DETERMINE MARGINAL LANDS IN MAGIC PROJECT

Previous country specific results, also used to develop MAGIC' model, derives from the study of Gerwin et al (2018) [55] carried out within SEEMLA project (described in the next section). This project investigated underused marginal lands for biomass production for energy purposes. Selected sites from Germany, Greece, and Ukraine represented a wide variety of different types of marginal lands. Based on a soil assessment based on Muencheberg' Soil Quality Rating (SQR) system, potential "marginal" sites have been investigated. The SQR system was adapted for use in a GIS study on marginal-land potentials in Europe. Thus, 46 % of the investigated European area could be classified as "marginal" with SQR scores below 40.

From that area 22.6 % can be considered as potentially suitable for producing renewable resources after eliminating protected sites or other places not suitable for any kind of land use.

A different approach is used by the study of Vera et al (2021) [56], which evaluates the available marginal land availability in EU for advanced biofuels production. The assessment has been conducted at 1-km^2 spatial resolution assuming spatiotemporal heterogeneity in biophysical conditions. The software R version 3.5.2 (2018-12-20) was used to carry out all the assessments and ArcMap 10.6.1 for map development.

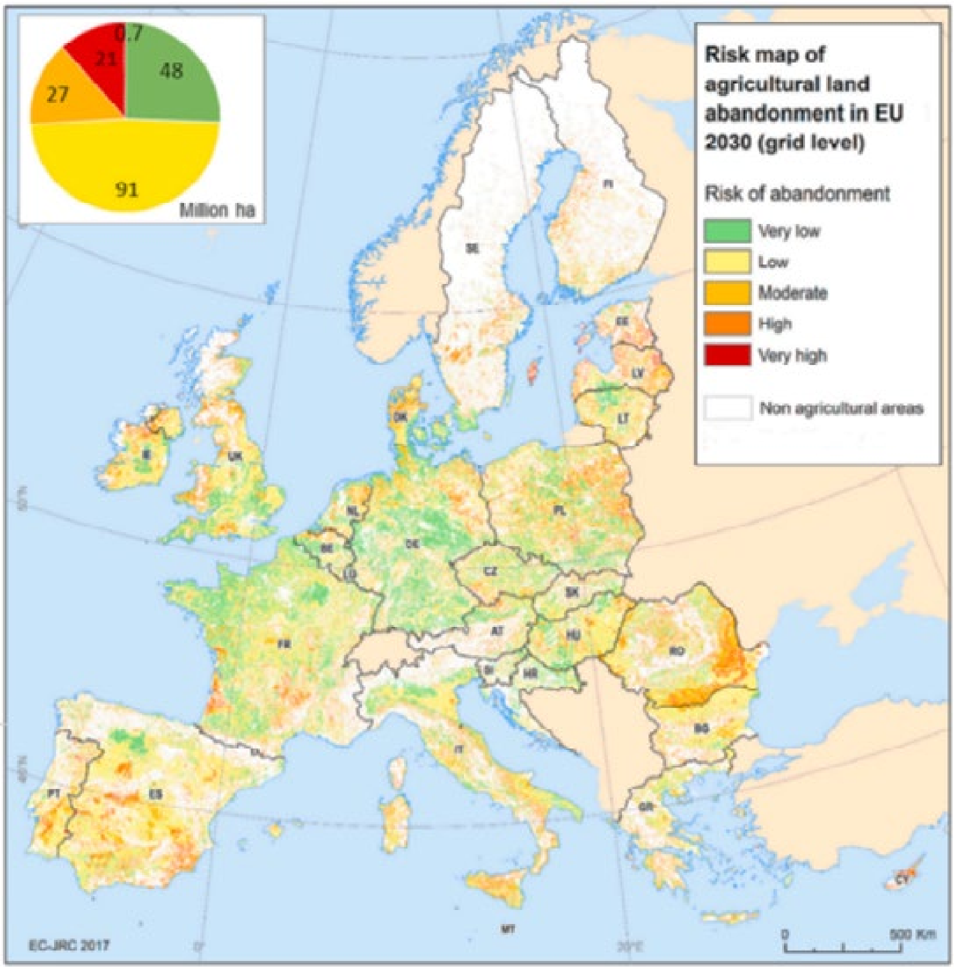

FIGURE 5 ESTIMATED POTENTIAL RISK OF AGRICULTURAL LAND ABANDONMENT IN 2030 AT GRID LEVEL (100M RESOLUTION) IN THE EU [52]

The results calculated an overall are set at 20.5 Mha for 2030 and 21 Mha for 2050, according to the guidelines set by the RED II sustainability criteria. However, the amount and location of land that meets REDII sustainability criteria vary over time due to LUC dynamics. For instance, Land-Use-based Integrated Sustainability Assessment modelling platform (LUISA, [57]) provides spatially explicit land-use/cover projections at a European level between 2020 and 2050 at a 10-year time step while considering economic, demographic and political drivers, including also biofuels scenarios [58].

The elaboration of LUISA' dataset performed by JRC [59] on lands abandonment in EU estimated (for the period 2015-2030) that the 11% (more than 20 million ha) of the total agricultural land available is under high potential risk of abandonment. Main factors are related to biophysical land suitability, farm structure and agricultural viability, population and regional specifics. In a more recent work [60], the estimated abandoned agricultural land in the EU and UK is more than 5.6 million ha. However, to estimate the potential of biofuels according to the RED II guidelines, additional disaggregation is needed.

Therefore, in literature there are some available peer-reviewed papers proposing further modelling exercises as reported here below.

- [61] estimated a total 16.2 Mha of identified abandoned cropland in Europe between 1992 and 2015, using maps from European Space Agency Climate Change Initiative (ESA CCI), where only 1.1 Mha were unsuitable for biofuels production.
- Other authors [62] investigated the concept of underutilized lands for biofuels production by using remote sensing techniques and 5-years temporal data from Sentinel' satellite. According to this study 5.2 Mha are suitable in Europe for Bioenergy production.
- Previous studies as the one of Galatsidas et al (2018) [63] reported that 64 Mha of land in Europe is marginal, based on the Muencheberg SQR. However, 53.7 Mha are considered suitable for biomass production due to ecological/ environmental issues or regulatory/legal restrictions and constraints posed by national or EU policies. This optimistic assessment was completed before the publication of the RED II. For this reason, papers coming before 2018 will not be considered.

5.2 Projects EU, National

Data on recent EU-funded projects performing experimental activities on project concerning marginal lands for biofuels production, are recapped here below.

TABLE 1: SOME INTERNATIONAL PROJECTS CONCERNING MARGINAL LANDS FOR BIOFUELS PRODUCTION

	Description & website	Duration	Consortium	Funding
BEE	Biomass energy Europe http://www.eu-bee.eu/	03/2008-11/2010	16 partners from Austria, Croatia, Finland, Germany, Greece, The Netherlands, North Macedonia, Poland, Sweden, Ukraine	EU research funding 2007-2013 7th framework programme (FP7) Overall budget: € 2 820 807
OPTIMA	Optimization of perennial grasses for biomass production http://www.optimafp7.eu/	10/2011 – 09/2015	21 partner from Belgium, Germany, Greece, Hungary, Ireland, Italy, The Netherlands, Portugal, Spain, The United Kingdom, and SICA members (Argentina, China, India)	EU research funding FP7 + Central American Integration System (SICA) Overall budget: € 3 913 249,84
WATBIO	Developing drought-tolerant biomass crops for Europe (poplar, miscanthus and *Arundo donax* L.) http://www.watbio.eu/	11/2012-10/2017	22 partners from France, Germany, Greece, Italy, The Netherlands, Spain, Sweden, The United Kingdom	EU research funding FP7-KBBE (knowledge-based bio-economy) Overall budget: € 11 660 401,40
FORBIO	Sustainable bioenergy production potential on available underutilized lands in Europe https://forbio-project.eu/	01/2016 - 12/2018	12 partners from Belgium, Germany, Hungary, Italy, Ireland, Poland, Romania, Ukraine, The United Kingdom	EU programme Horizon2020 € 1 941 581
SEEMLA	Sustainable exploitation of biomass for bioenergy from marginal lands http://seemla.eu/	01/2016 - 12/2018	8 partners from Germany, Greece, Italy, Ukraine	EU programme Horizon2020 € 1 629 884
MAGIC	Marginal lands for growing industrial crops http://magic-h2020.eu/	07/2017-06/2021	26 partners from Austria, France, Germany, Greece, Italy, Latvia, The Netherlands, Poland, The Portugal, Spain, Ukraine, The United Kingdom	EU programme Horizon2020 € 5 999 987,50

New-C-Land	Developing marginal land by producing plant biomass used for energy and materials https://www.newcland.eu/	01/2018-12/2021	9 partners from Belgium and France	Interreg France-Wallonie-Vlaanderen, co-financed by the European Regional Development Fund Overall budget: € 1 915 532
PANACEA	A thematic network to design the penetration PAth of Non-food Agricultural Crops into European Agriculture	11/2017 – 3/2021	18 partners from Netherland, Germany, Hungary, Italy, Ireland, Poland, Greece, France, Spain, Portugal, Romania, Lithuania, The United Kingdom	EU programme Horizon2020 (H2020-RUR-2016-2017) € 1 999 500,00

…

5.3 Tools

Besides peer-reviewed papers and technical reports estimating land availability , also web-tools mapping marginal lands are available.

- At European level, BIOPLAT-EU project developed a free tool [64] using a GIS platform. The overall objective of the project is to promote the market uptake of sustainable bioenergy in Europe using marginal, underutilized, and contaminated lands for non-food biomass production through the web platform aiming at decision based.
- The Horizon 2020 MSCA-RISE-2018 "MAIL" map portal [65] consists in web-GIS maps of marginal lands in Europe and a decision support system for afforestation planning. This portal is open for public use and allows users (even no experts in remote sensing techniques) to perform a variety of studies on marginal lands, including a Decision Support System (DSS). Other information are available here [66].
- The SEEMLA web application is built to provide assistance regarding the identification and exploitation of marginal lands for biomass production. Gerwin et al (2018) [55]reports methodology and results of the application of this tool within EU countries.
- The JRC dashboard concerning the EU SOIL OBSERVATORY - EUSO Soil Health Dashboard [67] indicates the number of soil degradation processes likely to be present in EU-27.
- IIASA developed MAGIC MAPS' application [68], which characterizes and analyses current and future marginal land in Europe facing natural constraints. The MAGIC decision Support System (DSS) [69] provides users with guidelines for industrial crops growing under marginal conditions in Europe [in BIKE D2.2 [19] maps and descriptions are present].

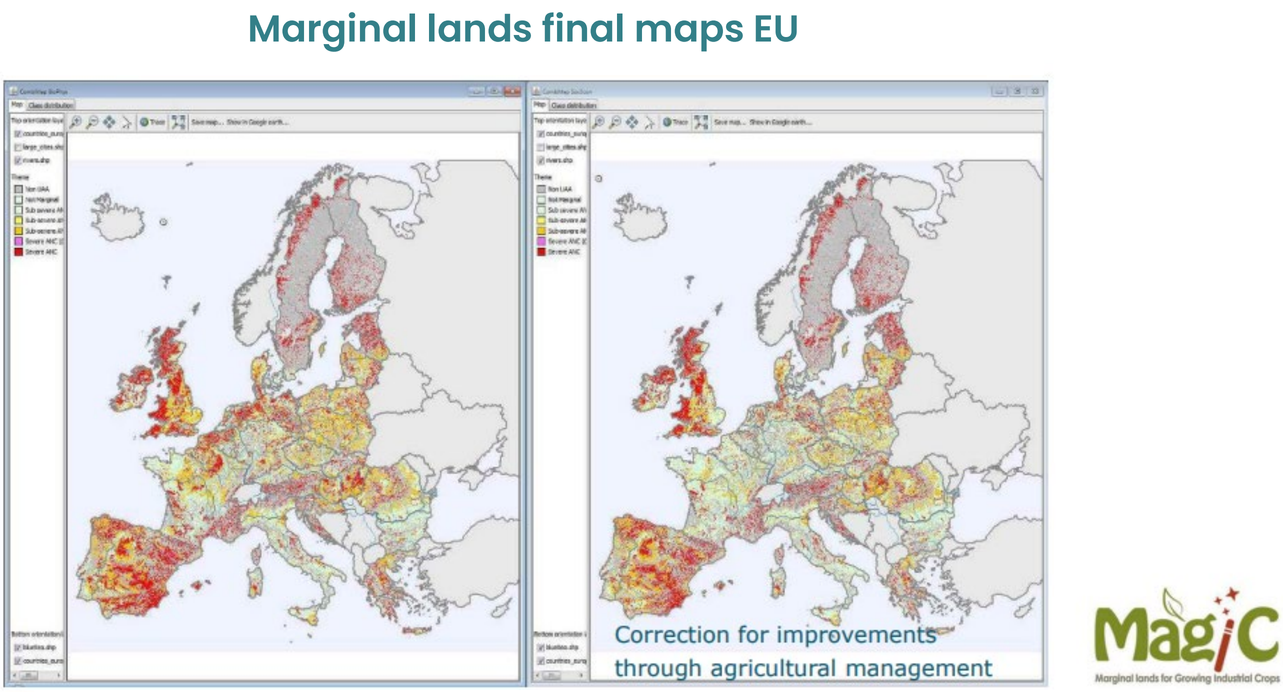

FIGURE 6 EXAMPLES OF MAPS FROM TABLE FOR GROWING ON MARGINAL LAND IN EUROPE [68]

6.

Mapping exercises
for contaminated lands

This chapter describes existing mapping exercises to identify land type, location, and areas for contaminated lands, existing EU and national projects, and issues on nutrients recycling from digesate use.

6 Mapping exercises to identify land type, location and areas for contaminated lands

6.1 Existing mapping exercises

Contaminated land mapping in Europe is not a straight forward task as there are a large number or variables to consider, that can not only change depending on the country, but also on a regional level. Toth et al (2016) [70] mapped heavy metals concentration as As, Cd, Cr, Cu, Hg, Pb, Zn, Sb, Co and Ni in European topsoil. While natural backgrounds might be the reason for high concentrations on large proportion of the affected soils, historical and recent industrial and mining areas show elevated concentrations (predominantly of As, Cd, Pb and Hg) too, indicating the magnitude of anthropogenic effect on soil quality in Europe. In a larger area which includes EU countries plus 12 neighboring ones (EEA39), JRC reported around 2.8 million potentially contaminated sites [37]. As regards available mapping exercises, as mentioned in the previous chapter, the BIOPLAT-EU project developed a free tool [64] to map contaminated sites in EU. As regards soil monitoring, the EU Soil Observatory (EUSO) [67] includes monitoring parameters as Mercury, Zinc and Copper, which are crucial to determine the status of a soil.

Thanks to recent developments reported in the mapping exercises developed in the last decades, recent H2020 projects (listed in the next section) selected specific sites to test phytoremediation solutions to restore contaminated soil, and at the same time, producing biomass for biofuels production. The H2020 GOLD project newsletter 2023 [71] reports a set of conclusions based on the mapping of point source pollution, but further work will be done to make this more comprehensive. The main conclusions from mapping point source pollution are as follows:

- Largest areas according to Open street map (OSM) as potential contaminated sites are military (41%), industrial and brownfields (29%), quarries (25%) and landfills (4%).
- The total area of potentially contaminated sites with land cover types suitable for phytoremediation, and with less than 40% of the area sealed (impervious), is 2,013,722 ha in the EU27 and UK (0.5% of the total surface area of these countries).
- France, Germany, Spain and UK have the largest total areas of all types of potentially contaminated sites (>150,000 ha each).
- Agriculture covers between 7% in military sites and 20% in landfills of the total area (OSM+CLC2018). These areas best suited for phytoremediation with biomass crops, because less effort is required for conversion of the land use.
- ‘Quarries’ in OSM overlap strongly with ‘Mineral extraction sites’ in CLC2018 (318,548 ha in EU+UK). However, 50% of the CLC2018 ‘Mineral extraction sites’ do NOT overlap with OSM ‘Quarries’. So, for their identification we need to combine OSM and CLC band we expect a total area of >600,000 ha in EU+UK.
- Of the total of 20,708 mines observed in land cover classes considered relevant for phytoremediation, almost half (10,206 mines) are located in agricultural land. These findings suggest a large potential for

phytoremediation using biomass crops on existing and likely polluted agricultural lands.

- In the group of mines with high risk for human health with commodities suitable for phytoremediation, the largest numbers of mines are estimated likely to be treated with phytoremediation through extraction of contaminants (28% of total) or stabilization of the contaminants (37% of total).

6.2 Projects EU, National

Three Horizon Europe projects (GOLD , Phy2Climate, & CERESiS) are working together on phytoremediation solutions since they took part in the same call to achieve 'Combined clean biofuel production and phytoremediation solutions from contaminated lands worldwide' [72]. Dedicated biofuel production at large scale depends on sustainable land availability that does not compete with other uses. Phytoremediation is a holistic approach that has the potential to manage land contaminated with a wide range of pollutants. Therefore the challenge faced by all three projects is to bridge the gap between phytoremediation strategies and clean biofuel production in a sustainable and optimum manner that will overcome the indirect land use change (iLUC) issue for biofuels and restore lands for agricultural uses.

TABLE 2: SOME INTERNATIONAL PROJECTS CONCERNING PHYTOREMEDIATION FOR BIOFUELS PRODUCTION.

Abbreviation	Description and Website	Duration	Consortium	Funding
GOLD	Bridging the gap between phytoremediation solutions on growing energy crops on contaminated lands and clean biofuel production https://www.gold-h2020.eu/	5/2021 to 5/2025	20 partners coordinated by CRES (CENTRE FOR RENEWABLE ENERGY SOURCES AND SAVING FONDATION), Greece	H2020-LC-SC3-2020-RES-RIA Overall budget: € 3 818 421,25
CERESis	ContaminatEd land Remediation through Energy crops for Soil improvement to liquid biofuel Strategies https://ceresis.eu/	11/2020 to 5/2024	12 partners coordinated by ETHNICON METSOVION POLYTECHNION, Greece	H2020-LC-SC3-2020-RES-RIA Overall budget: € 4 042 885,01
Phy2Climate	A global approach for recovery of arable land through improved phytoremediation coupled with advanced liquid biofuel production and climate friendly copper smelting process https://www.phy2climate.eu/	1/2021 to 7/2025	17 partners coordinated by ITS FORDERBERATUNG GMBH, Austria	H2020-LC-SC3-2020-RES-RIA Overall budget: € 4 151 989,00

The first step in bridging the gap is by determining the best energy crops to grow on contaminated soil, that will not only facilitate the remediation of the soils but will also provide the highest yield of feedstock for producing liquid biofuels. All three projects have now completed at least one year of field trials but there are no still sufficient documentation to report reliable results to propose within the BIP.

As regards CERESiS, the project is in its final year of research and will present the conversion and contaminant separation technologies used and share with us some the most important results of the project. It is worth noting that Deliverable 1.5 identified several sustainability Key Performance Indicators (S-KPIs) for integrated solution pathways and Deliverable 1.4 addressed the regulatory & policy framework for contaminated land management and biofuels. Such documents are publicly available in the project' website.

GOLD recently just completed its half pathway of activities, testing different biomasses for phytoremediation. Produced biomass will be then thermochemically processed by gasification to produce biofuels from syngas and retaining contaminants in the by-products [71].

Phy2Climate' researchers recently published a paper [73] investigating non-food biomass generated as a result of phytoremediation that could provide a meaningful low ILUC-risk feedstock for the production of advanced biofuels. This paper addresses the policy and legal background surrounding the uptake of phytoremediation solutions, offering an updated overview on the available options to generate opportunities for both heavy metals retention and biofuels production.

Finally, another project already mentioned in the document, i.e. BIKE [19], elaborated MAGIC' maps to evaluate the suitability of certain crops for phytoremediation solution. This project, as proposed by other authors [74], investigated the cultivation of Giant Reed for this proposal, that can be used also as feedstock for biomethane production (retaining contaminants into the digestate).

6.3 Issues on nutrients recycling from digestate use

Nutrient utilization plays an increasing role in the business cases for biogas (and bio methane) production. The suitability of a digestate for fertilizer use must be assessed early in the process to avoid misleading business cases. Digestate from biogas production is typically exempted from registration under REACH EC/1907/2006 due to Annex V, as established by regulation EU/2019/1691. Accordingly, the digestate is exempted only if derived from non-hazardous materials. Thus, a digestate from potentially contaminated crops is likely not exempted from REACH registration. However, the toxicology of a digestate obtained from contaminated land must be assessed in line with REACH regulation. The necessary assessment will provide information about the hazardous-ness, environmental and storage and handling requirements; those specifics must be stated in the dossier for registration as well as the safety data sheet (SDS). The EU Classification, Labeling and Packaging regulation (CLP) EC/1272/2008 is applicable, too, if the material is considered hazardous. Requirements for transport and storage of the biogas plant feedstock (crops grown on contaminated land) and the obtained digestate arise by the hazardous substances and their concentration in the materials. The registration under REACh as well as consequences out of CLP will likely imply costs which needs to be addressed in the business case.

The EU Fertilizing Products Regulation EU/2019/1009 (FPR) allows digestate under the CMC 4 (energy crop digestate) and CMC 5 (other digestate):

The definition of CMC 4 has a blind spot, which may need to be addressed with the EC: The CMC 4 definition does not include requirements on contaminants of crops or the soil the crops grew on. Furthermore, CMC 4 entitles to conduct the conformity assessment module A, which is the simplest one without involvement of a notified body or a quality management system in place. This combination indicates an anticipated low risk level, and that CMC 4 is not intended to address matters of hazardous substances.

Potentially hazardous feed stock is excluded under CMC 5, as such materials likely do not meet the requirements of bio-waste as set out by the waste framework directive EC/98/2008. CMC 5 requires an extensive conformity assessment module D1 application, which is more suitable to address contaminants.

Therefore, FPR may not regulate the relevant hazardous contaminants in the PFC 1 or 2, hence digestate from contaminated biomass needs further assessment before its use, to avoid potential spread of contaminants across the EU internal borders.

7. Biomass type and potential from marginal lands

This chapter quickly reports the most recent findings available from projects and peer-reviewed papers mentioned in the previous chapters.

7 Estimation of biomass type and potentials from marginal lands

This chapter quickly reports the most recent findings available from projects and peer-reviewed papers mentioned in the previous chapters.

- Horizon2020 BIKE Deliverable 2.2 [19] and Panoutsou et al (2022) [24] studied potential biomass feedstocks that can be cultivated in unused, abandoned or severely degraded land. The work strongly builds on recently finished work in the EU projects of the European projects S2Biom, MAGIC, PANACEA, SoilCare, BIO4A and BECOOL and the DG-ENER" contract study on the status of land availability in the EU and use for energy and other non-food crops [31]. Biomasses are grouped as either oil-based, or lignocellulosic biomass, while crops yield is given for Atlantic, Continental and Boreal, and Mediterranean climatic zones (as shown in **Error! Reference source not found.**). For details of biomass type (e.g. annual or perennial), including a detailed description of the key characteristics for biofuels/biogas conversion, BIKE Deliverable 2.2 [19] summarizes recent and previous findings from the most recent experiences (e.g. MAGIC' project).

- Observed attainable crops yield and potential yield increases for biomasses from conventional farming land conditions compared to lands with natural constraints have been further discussed in Panoutsou et al (2022) [24], including estimates on cost of feedstock per ton. Specific crops yield and costs for the selected biomass sources per EU country are also reported in Ramirez-Almeyda et al (2017) [75]. Summarizing, economics of growing and harvesting feedstocks on marginal or degraded land result in a cost per ton of harvested feedstock higher than the one from arable agricultural land.

Table 3 Yields and type of agricultural practices for different European Agro-Ecological Zones-AEZ (A: Atlantic, C&B: Continental and Boreal, M: Mediterranean) considering specific selected crops suitable for marginal lands [19].

		Agricultural Practices*	Average Baseline Yields (t/ha Seeds for Oil Crops and t/ha Dry Matter Biomass for Lignocellulosic Ones) per AEZ** (in Parenthesis Yields in marginal Land (with Natural Constraints)		
			A	C and B	M
	Ethiopian mustard	B, UAD	3.5 (1)	na	2.5 (1.5)
	Crambe	B, UAD	2 (0.5)	2.5 (1)	3 (1)
	Camelina	I, CC, R, B, UAD	2.5	2 (1)	3 (1)
	Cardoon	B, UAD	3 (1.5)	3 (1.5)	3.5 (1.5)
	Castor	I, B, UAD	na	na	3.5 (1.5)
Lignocellulosic	Willow	AF. B, UAD	12 (6)	12 (6)	13 (4.5)
	Poplar	AF, B, UAD	10 (8)	10 (7)	10 (4)
	Biomass sorghum	I, R, B, UAD	15 (9)	15 (9)	20 (12)
	Tall wheat grass	B, UAD	na	na	10 (7)
	Miscanthus	B, UAD	12 (8)	15 (9)	20 (9)
	Switchgrass	B, UAD	18 (10)	18 (10)	20 (12)
	Cardoon	B, UAD	14 (8)		20 (10)
	Giant reed	B, UAD	15 (9)	15 (9)	20 (11)
	Reed canary grass (RCG)	B, UAD	15 (7)	15 (7)	20 (7)

- Estimates of biomass potentials from degraded/marginal abandoned lands can refer to the study conducted by the Imperial College London Consultants for Concawe, “Sustainable biomass availability in the EU towards 2050 (RED II Annex IX Part A/B)” [76]. In this study, three scenarios have been modelled (agriculture, forestry and wastes), and the major challenges were for agriculture, which considered also a growing share of unused, degraded, and abandoned land for producing biomass for advanced biofuels production (according to Annex IX part A).

Where the results have been updated in a more recent report of Concawe [77] elaborating data for Biomass availability excluding potential demand for non-energy uses (i.e. biomass potentials for bioenergy in transport, heat and power) in the EU and UK in 2030 and 2050. The estimated figures range from 520–860 million dry tonnes (208–344 Mtoe) for 2030, and from 539–915 million dry tonnes (215–366 Mtoe) for 2050 (see **Error! Reference source not found.**). Biomass from the categories investigated in Table 4 consists in “lignocellulosic crops”. This category considers the most suitable energy crops based on the selected territory (climate zone, soil type, etc.).

TABLE 4 MAIN ASSUMPTIONS FOR THE THREE SCENARIOS EXAMINED IN THE IMPERIAL COLLEGE LONDON STUDY [76]

Agriculture	Scenario 1 (Low)	Scenario 2 (Medium)	Scenario 3 (High)
Removal rate of field residues	40%	45%	50%
Use of prunings	5%	20%	50%
Moderate yield increases in perennial lignocellulosic crops in unused, degraded, and abandoned land.	1%	1%	2%
Share of unused, degraded, and abandoned land for dedicated crops, excluding biodiversity rich land and land with high carbon stocks.	25%	50%	75%

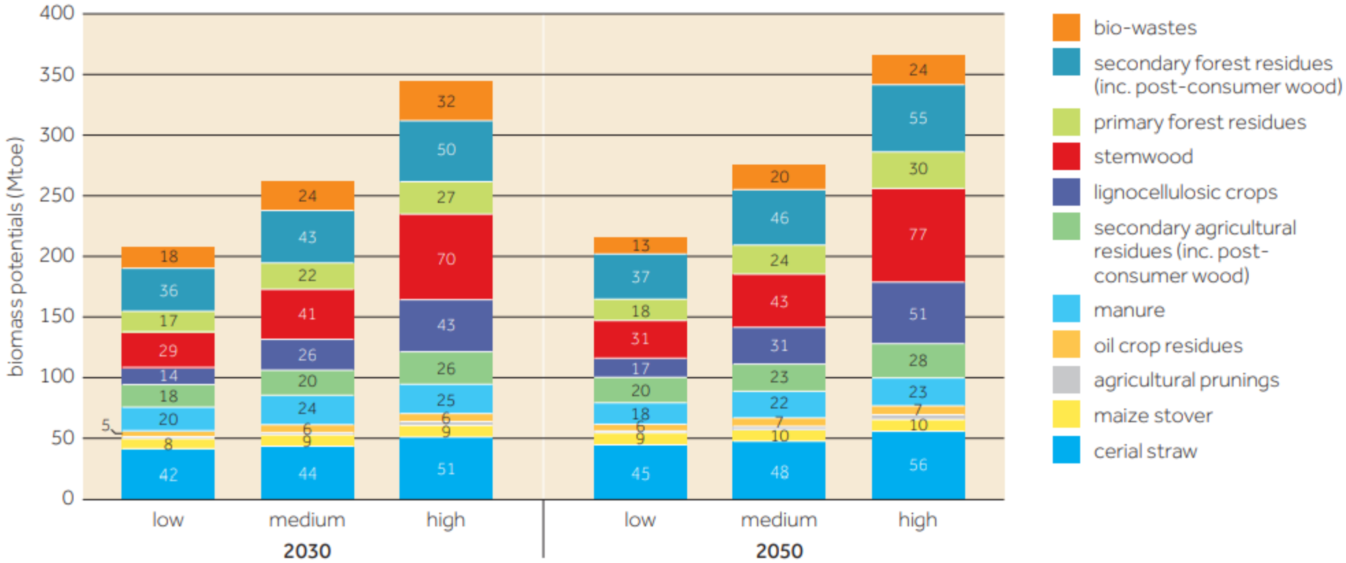

FIGURE 7 ESTIMATED SUSTAINABLE BIOMASS POTENTIALS (RED II ANNEX IX, PARTS A AND B) THAN CAN BE AVAILABLE [77]

The same report reports the impact assessment confronting such results with one performed by DG RTD study [78] and the model TIMES (ENSPRESO database) performed by JRC and reported in a recent EC working document [79].

Imperial College's estimation of biomass availability in the High scenario is 22% higher than in the DG RTD high scenario, and 26% lower than JRC TIMES high scenario. The JRC TIMES high scenario gives the technical maximum that can be achieved, without sustainability criteria, allowing dedicated cropping in high biodiversity lands and including first-generation biofuel crops. However, these estimates should be re-evaluated for future projections within the updated EU climate targets.

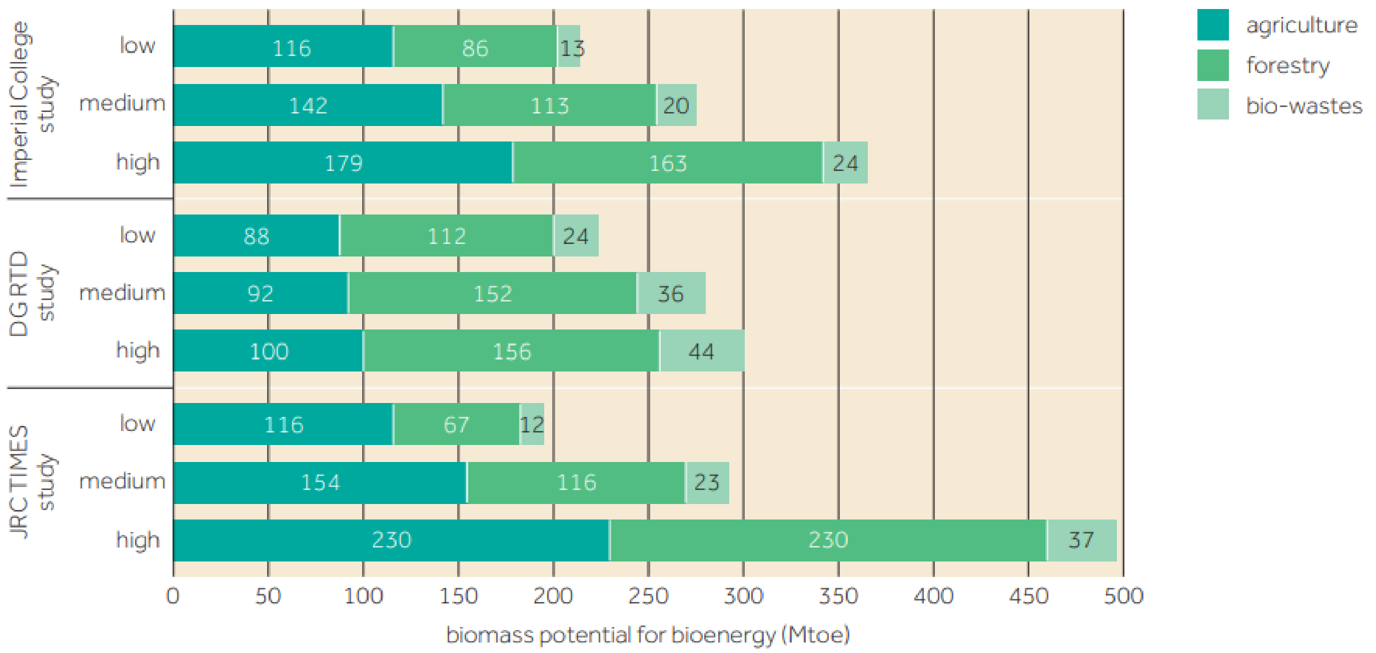

FIGURE 8 COMPARATIVE ESTIMATES FOR BIOMASS POTENTIALS (MTOE) FOR BIOENERGY IN THE IMPERIAL COLLEGE, DG RTD AND JRC TIMES (ENSPRESO DATABASE) STUDIES FOR 2050 [77]

8 Conclusory remarks

Today there are no commercial activities considering biomethane from contaminated biomass (including potential contaminated digestate) and/or biomass from degraded lands. EU projects are still at early stage of developments, proposing modelling exercises and small-scale experimental trials. However, new policy frameworks on agricultural, biodiversity, climate and energy sectors may create opportunities to develop new business models for farmers and biomethane operators. Low ILUC-risk feedstock certification for biomass supply, RED II Annex IX' revision and carbon farming are key-opportunities that may trigger new supply chains for advanced biofuels production.

Remarks on marginal land

- Definitions of lands type (considering the current legislative framework, e.g. REDII, CAP, Soil-related policies) have been provided, but still not harmonized in the existing legislation. A joint effort to harmonize land classification up to regional level is needed.

- There is not just one best model to be exported for all EU-27, but different combinations resulting from the best integrations of crops, climatic regions and applied GAPs. The results of recent H2020 projects and European Commission' studies have already identified specific case studies where best practices can be applied.

- Marginal lands recovery should deliver benefits for the farmer, otherwise there will be no convenience either to expand agriculture, or to recover abandoned lands.

- If marginal land delivers lower yields or biomass supply derives from remote areas, the risk of having no profit for the farmer is high or the price of crops results higher compared to cultivated non-marginal land. Therefore, economic support deriving from a combination of energy, climate, soil and agriculture supporting schemes have the potential to cover the current gap.

- Marginal lands and grasslands need further assessment (in particular at National level):

    - if the land is simultaneously degraded and grassland, investments are limited by different restrictions covering both land categories;
    - grasslands cannot be reconverted to cultivated lands, as the CAP does not allow to plough grassland for cultivation;
    - grassland can be used for biomethane production whether without high value for biodiversity, or with recognized high value for biodiversity, mowing when necessary to maintain a good conservation state;
    - statistics about marginal land has to be checked carefully, as many of those areas could be already grassland and would not be available for bioenergy crops.

- Biomass supply should involve a combination of best available practices in selected areas (carried out from the experience of recent H2020 projects) and harmonized policy frameworks to create new business models for long-term investments.

- Opportunities from the existing policy framework are recapped here below.

Energy policies Green Deal, RED II, RePowerEU	**CAP**	**Farm-to-Fork and Climate Targets**	**Biodiversity**
• Biomass supply to achieve the mandate for advanced biofuels production (no food/feed competition) • Contributing to achieve 35 bcm biomethane target with sustainable feedstock • Contributing to reduce GHG emissions using low ILUC-risk feedstock • GHG emissions crediting system for marginal lands recovery and soil organic carbon increase	• Recovering lands for agriculture • Promoting new soil restoration techniques using catch-, cover-, inter-cropping • Using digestate to recover degraded soil and to reduce synthetic fertilizers • New business models for farmers based on biomethane/biochemicals and food & feed production • Food security	• Promoting carbon farming according to the sustainable carbon cycles target • Protecting soils, reducing soil loss by erosion, and enhancing soil organic carbon on degraded arable land • Biological carbon capture opportunities	• Recovering degraded soils • Recovering lands/areas to restore biodiversity (reafforesting, restoring native plants, ...) • Contributing to carbon sequestration • Restoration of contaminated areas • Restoration of peatlands and wetlands reducing oxidation of existing carbon stock

Remarks on contaminated land

- Contaminated soils mapping exercises, biomass phytoremediation potential and biomethane productivity have still to be further studied. However, the experience from ongoing H2020 projects is showing real opportunities for biomethane and biofuels from feedstock retaining heavy metals and other contaminants.

- Phytoremediation solutions should be assessed per case study (varying per Country), with a full life cycle analysis of the biomethane produced, including by-products.

- Depending on the type of contamination and the phytoremediation strategy selected, different contaminants accumulation into the crop can occur. If the contamination ends in methanisation residue (digestate), it would be impossible to closed the loop of the circular economy to recycle the nutrients of the digestate. The cost of handling this digestate and puting it into a dump (due to contamination) must be included in all cost calculations and reflections (e.g. REACH registration), creating barriers to develop new business models for biomethane operators.

- If contaminated land is turned into grassland the same problems as for ploughing marginal land will appear.

- The EU Soil Monitoring Law could introduce a binding identification and remediation of contaminated lands. This may trigger some business cases for biogas or biofuels production using phytoremediation solutions, because the legally responsible owner of contaminated lands might be required to implement additional risk reduction measures (implying costs), aimed to reduce the soil contamination level to acceptable ranges for human health and environment.

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