Alma Mater Studiorum – Università di Bologna

DOTTORATO DI RICERCA IN

Scienze e Tecnologie Agrarie, Ambientali e alimentari

Ciclo XXIX

Settore Concorsuale di afferenza: *07/B1*

Settore Scientifico disciplinare: *AGR/02*

LIGNOCELLULOSIC CROPS IN EUROPE: INTEGRATING CROP YIELD POTENTIALS WITH LAND POTENTIALS

Presentata da: *Jacqueline Ramírez Almeyda*

Coordinatore Dottorato

Prof. Giovanni Dinelli

Relatore

Prof. Andrea Monti

Correlatori

Dr. Berien Elbersen

Dr. Nicola Di Virgilio

Esame finale anno 2017

Dedicado
A mis queridos padres, Juvencio Ramírez y Vilma Almeyda por todo el amor y compresión.

A mis queridos Filippo, Imma, Igor y Berien, que fueron pieza fundamental en esta aventura.

Jacqueline Ramírez Almeyda

Lignocellulosic crops in Europe: Integrating crop yield potentials with land potentials.

PhD. Thesis on Agricultural, Environmental and Food sciences and Tecnologies. XXIX Ciclo, University of Bologna.

Thesis supervisor: Dr. Andrea Monti - Department of Agricultural Sciences (DipSA), University of Bologna, Viale G. Fanin, 44, 40127 Bologna, ITALY.

Thesis Co-Supervisor: Dr. Berien Elbersen - Wageningen Environmental Research, PO Box 47, NL-6700 AA, Wageningen, The Netherlands.

Thesis Co-Supervisor: Dr. Nicola Di Virgilio - National Research Council of Italy, Institute of Biometeorology, via P. Gobetti, 101, 40129 Bologna, Italy.

Research collaboration: Igor Staritsky, Raymond Schrijver, Kees van Diepen – ALTERRA - Wageningen Environmental Research, PO Box 47, NL-6700 AA, Wageningen, The Netherlands.

ABSTRACT

Ramirez Almeyda J., 2017. **Lignocellulosic crops in Europe: Integrating crop yield potentials with land potentials.** Doctoral Thesis, University of Bologna, Italy.

Given the ambitious EU targets to further decarbonise the economy, it can be expected that the demand for lignocellulosic biomass will continue to grow. Provisioning of part of this biomass by dedicated biomass crops becomes an option. This study presents integrated approach for crop allocation based on land availability and crop requirements. The model analysis to investigate the potential extension of unused land and its suitability for lignocellulosic crops was carried out in 37 European countries at the NUTS3 level. The CAPRI model predicts future land use changes and was used as a basic input to assess the agricultural biomass potentials in Europe. It was then identified the total land resource with a post-modeling assessment for three different potentials to the year 2020 and 2030, according to sustainability criteria formulated in the Renewable Energy directive (RED). That remained unused land after subtracting the land used for food, feed and 1G biofuels as predicted in the CAPRI baseline scenario. Furthermore, crop-specific suitability maps were generated for each crop based on the variability of biophysical factors such as climate, soil properties and topographical aspects. The yields and cost levels that can be reached in Europe with different perennial crops in different climatic, soil and management situations. The AquaCrop model developed by FAO was used and fed with phenological parameters per crop and detailed weather data to simulate the crop growth in all European Nuts 3 regions. Yield levels were simulated for a maximum and a water-limited yield situation and further converted to match with low, medium and high input management systems. The costs production was assessed with an Activity Based Costing (ABC) model, developed to assess the roadside Net Present Value (NPV) cost per DM Mg ha^{-1} of biomass. The yield, crop suitability and cost simulation results were then combined to identify the best performing crop-management mix per region.

Keywords – Lignocellulosic crop, Biomass potentials, Unused lands, Released land, Land suitability, Economic Models

TABLE OF CONTENTS

List of Acronyms and Abbreviations

ABC	Activity Based Costing
COP	United Nations Climate Change Conference
CAP	Common Agricultural Policy
CAPRI	Common Agricultural Policy Regionalised Impact
CLC	Corine Land Cover
EU28	European Union members
EEA	European Environment Agency
FADN	Farm Accountancy Data Network
FAO	Food and Agriculture Organization of the United Nations
FSS	Farm Structural Survey
GIS	Geographic Information System
GAMS	General Algebraic Modelling System
GHG	Greenhouse gases
GDD	Growing degree days
JRC	Joint Research Centre
MARS	Monitoring of agriculture with remote sensing
Mha	Million hectares
NECR	New Energy Crops
Non-EU	Neighbouring Central and eastern European countries
NUTS	Nomenclature of Territorial Units for Statistics (of the European Union)
NREAPs	National Renewable Energy Actions Plans
NPV	Net Present Value
HNV	High Nature Value farmland
GWSI	Global Water Satisfaction index
PBC	Perennial Biomass Crop
RED	Renewable Energy Directive
RCG	Reed canary grass
SRC	Short Rotation Coppice
UAA	Utilised Agricultural Area
1G	First generation
2G	Second generation

List of Tables and Figures

Tables

Figures

Annex

GENERAL INTRODUCTION

The universal agreement on climate change reached in the last COP21 conference is aimed to keep a global temperature rise "well below" 2ºC by the end of this century and to drive efforts to limit the temperature increase even further, down to 1.5 ºC above pre-industrial levels (United Nations, 2015). For this purpose, a framework was adopted by EU leaders with specific goals: 40% cuts in greenhouse gas emissions (compared to 1990 levels), 27% share of renewable energy and 27% improvement in energy efficiency by 2030 (European Commission). In this context, National Renewable Energy Actions Plans (NREAPs) consider the production of biomass from lignocellulosic crops, which can play a key role in the development of renewable energy sources in Europe. Definitely, there are several reasons to promote bioenergy crops (Don et al., 2012). Currently, the 93% of the domestically grown bioenergy crops are converted into biodiesel and first-generation bioethanol (Biomass Futures). But nowadays the focus is on the production of second-generation biofuels at commercial scale due to their environmental benefits such as soil erosion mitigation, soil protection, high biodiversity, including farmland bird diversity, reduced GHG emissions, greater carbon sequestration and low impact on water availability (Alexopoulou et al., 2015; Zegada-Lizarazu et al., 2010; Richter et al., 2016; Alexopoulou et al., 2010).

This study was carried out in the framework of the EU project S2Biom, aimed at developing an innovative support tool to analyse the potential of lignocellulosic crops in 28 European Member States and nine neighbouring Central and eastern European countries[1] at the NUTS3 level. The project predicts both sustainable supply and cost of solid lignocellulosic biomass from forestry, dedicated energy cropping, agricultural residues and secondary residues from wood, food industry and waste. The focus in the present study was on dedicated energy cropping (herbaceous and short rotation coppice), and their most representative species for second-generation feedstock in Europe. The data accumulated during many recent European projects (See Table 1) were important and useful to the selection. Hence, eight species were selected based on their productivity, geographical distribution and literature abundance as compared with other species used for energy purposes (Perpiña Castillo et al., 2015). Five herbaceous perennial crops and three short rotation coppice (SRC) were included: (i) herbaceous perennials: miscanthus (*Miscanthus* spp.), switchgrass (*Panicum virgatum* L.), giant reed (*Arundo donax* L.), reed canarygrass (*Phalaris arundinacea* L.),

[1] Neighbouring Central and eastern European countries: Albania, Bosnia & Herzegovina, Montenegro, Republic of Macedonia, Kosovo, Serbia, Turkey, Moldova and Ukraine.

cardoon (*Cynara cardunculus* L.) and (ii) short rotation coppice: willow (*Salix* spp.), poplar (*Populus* spp.), eucalyptus (*Eucalyptus* spp.).

Table 1 Relevant European projects evaluating biomass crops performance and suitability. Table modified from Dees et al., 2017b.

Project	**Description**
S2Biom http://www.s2biom.eu/en/	Project (2013-2016) covered the whole biomass delivery chain - from primary biomass to end-use of non-food products, and from logistics and pre-treatment to conversion technologies. These aspects have been elaborated to facilitate integrated design and evaluation of optimal biomass delivery chains and networks at European, national, regional and local scale.
4FCROPS	Completed in 2010 and delivered a lot of reports and publications on the most viable crops for non-food biomass production (either for energy production or biobased materials) in every environmental zone in the EU, cost structure and economic and environmental performance of the different crops. The project also made an estimate of the land availability for these crops at different time frames which could also provide further information on land identification.
BiomassFuture http://www.biomassfutures.eu/	The Intelligent Energy Project, Biomass Futures (2009- 2012), resulted 2012, estimated the role biomass can play to meet the 2020 RED targets at EU27 through a demand-supply analysis and extensive consultation with stakeholders across Europe. To do so it developed a systematic Biomass cost supply Atlas for EU27 and the RESolve model to address the competition of biomass supply in the three energy markets (heat, electricity and transport). Furthermore, a set of sustainability criteria and indicators for bioenergy was developed which goes beyond the RED to address all bioenergy.
OPTIMA http://www.optimafp7.eu/	was an EU project (completed in 2015 that aimed at identifying high-yielding perennial grasses for the Mediterranean area, within optimized production chains (for both energy and new plant derived bio-products). The focus was particularly on identifying and evaluating the best performing crops, genotypes and farm management systems when grown on underutilised and/or abandoned marginal in Mediterranean environments.
FIBRA http://www.fibrafp7.net/	project (2012-2015) collected and analysed valuable information on most suitable fibre crops and genotypes as sustainable sources of biobased material for industrial crops covering the whole production chain and following the biorefinery concept.
Water4Crops http://www.water4crops.org/	stands for can provide information on suitable crops and their performance bio-treatment of wastewater in Europe.
OPTIMISC https://optimisc.uni-hohenheim.de/	The overall objective of OPTIMISC was to optimize the *miscanthus* bioenergy and bioproducts chain by: trialling elite germplasm types over a range of sites across Europe; analyzing the key traits that currently limit the potential of miscanthus; identifying high-value bioproducts; modelling the combined results to provide recommendations to policy makers, growers and industry.

GrassMargins http://www.grassmargins.com/	The project studies the potential for using different types of grass species under challenging climatic conditions (e.g. drought, salinity, flood and cold) to develop high yielding biofuel crops. The selection of material by partners in the project focusses on *miscanthus* and *giant reed* taxa.

Specific objective of the present study:

To estimate biomass yield potential of lignocellulosic crops and their sustainable allocation in EU28[2] and in nine neighbouring countries at NUTS3 level in 2020 and 2030.

Structure of the thesis

- ***The first chapter illustrates the unused land potentially available and suitable for lignocellulosic crops.*** Unused land availability was predicted on the base of the CAPRI[3] model and post-model assessment. Furthermore, RED[4] sustainable criteria were considered to generate three types of potentials for the year 2020 and 2030 and crop specific suitability maps were generated for each crop according to biophysical factors such as climate, soil properties and topographical aspects.
- ***The second chapter describes an approach to simulating yields.*** Quantitative and qualitative traits of selected crops were summarized in a specific database on the base of an extensive review. Yield simulations were made for the selected crops with the Aquacrop model developed by FAO, predicting "yield response to water". Yields were calculated for three input system levels (low, medium & high) to consider different cropping situations & policies around EU and to address different decision makers.
- ***The third chapter describes the integrated approach for crop allocation based on land availability and crop requirements.*** The results for the land potential, crop-specific suitability (Chapter 1), crop yield estimation (Chapter 2) and production cost, were integrated with the purpose is to identify three crops combination able to provide the highest yields with lowest costs in unused land in Europe.
- ***The general conclusions.***

[2] The study area has included United Kingdom
[3] CAPRI: Common Agricultural Policy Regionalised Impact analysis model
[4] RED: Renewable Energy Directive

CHAPTER 1

Dedicated Cropping Biomass Potential on unused lands in Europe

Foreword

Land is today a sensitive issue as it is a scarce resource in most parts of the world. Nonetheless, many lands in Europe have been released from the agricultural use due to socio-economic and climatic reasons, becoming unused. *This chapter presents a modelling approach to investigate the potential extension of unused land and its suitability for lignocellulosic crops.* The analysis was carried out in 37 European countries at the Nuts3 level. The CAPRI model predicts future land use changes and was used as a basic input to assess the agricultural biomass potentials in Europe. Thus, unused land was estimated using CAPRI disaggregated from NUTS2 to NUTS3, then was identify the total land resource with a post-modeling assessment for 3 different potentials (years 2020 and 2030), that remained unused after subtracting the land used for food, feed and 1G biofuels as predicted in the CAPRI baseline scenario. The three "unused land" potentials were therefore generated: *Technical Potential*, *Base Potential* and *Strict Sustainability Potential* according to sustainability criteria formulated in the Renewable Energy directive (RED). Furthermore, crop-specific suitability maps were generated for each crop based on the variability of biophysical factors such as climate, soil properties and topographical aspects.

INTRODUCTION

Nowadays, European strategies show a lot of interest in lignocellulosic material as a way to mitigate climate change. Given the expected increase in the energy demand, it is likely that non-food biomass crops will start to play a growing role in the supply of biomass. These crops are an interesting resource provided that they can be produced on lands that are not used for food and feed production and that, by cultivating them, no additional pressure is placed on scarce natural resources such as water and biodiversity. This implies that their suitability and yield performances on lower productive lands, in particular, need to be better understood.

According to Elbersen et al. (2012), ETC/SIA, (2013) and Allen et al. (2014), bioenergy crops represent the 3.2% of the total agricultural area, which is about 5.5 Mha. The 81% of this surface is used for oil crops (rape and sunflower), 11% for ethanol crops, 7% for energy maize (biogas), while only the 1% is used for perennial biomass crops. The amount of land of dedicated crops - commonly known as *perennials biomass crop* (PBC) - is currently very low. For instance, the European Bioenergy Outlook (AEBIOM, 2013) and Lewandowski et al., (2015) reported that between 60,000 to 115,000 ha are presently grown in Europe with switchgrass, reed canarygrass, poplar, miscanthus and willow. However, for some regions, these surfaces are likely underestimated since perennial biomass crops are not well established in the common EU agriculture and are not included into national crop databases or in Eurostat.

Land availability potential in Europe ranges between 1.34 Mha (Allen et al., 2014) to 12 Mha (Alexopoulou et al., 2010; ETC/SIA, 2013). But, lack of data allowing the identification of categories of land relatively precise is a severe impediment, and so is location/total extent of land with any accuracy. As a consequence, assessments and modeling approaches are necessary (Allen et al., 2014).

Hence, in order to perform an analysis of potential non-food biomass production, first, it was necessary to develop an approach to estimate land availability. We attempted to assess how many specific areas were released from agriculture in the last years and to predict future land abandonment. In the present chapter, a model built to predict future land use changes called CAPRI and post-model assessments are shown. These tools were used in the European Project S2BIOM project to assess potential biomass production and its cost-supply potential. The chapter, eventually, discusses the advantages and limitations of modeling approaches in assessing future biomass supplies and points further work that can be done to tackle these limitations.

BOX 1. Land categories for perennial biomass cultivation

The lack of data defining relatively precise categories of land which could be suitable for energy crops, is a severe impediment to pinpoint either the location or estimate the total surface extent of such land with any accuracy (Allen et al.,2014). According to Dauber et al., 2012, **Surplus Land** can be the umbrella term embracing all potentially available areas for bioenergy cultivation including fallow land, set aside, abandoned land, marginal land, degraded land, reclaimed land and waste land. The identification of available land for bioenergy crops is therefore the first milestone to to consider specific crops, predict bioenergy yields and plan facilities location for biomass biochemical conversion.

For each surplus land type concept and the estimated area are briefly described below:

Fallow land (or idle land) is agricultural land that has not been cultivated for one year as part of a crop rotation program, or for multiple years. Fallow land is neither cropped nor abandoned as is still within the productive agricultural cycle (Allen et al., 2014). Fallow land can provide environmental benefits, such as rebuild soil fertility, prevent accumulation of pest and disease in neighbouring crops as the land remains covered by vegetation. The report by UNICT (2009a) estimated 20.3 million hectares of fallow land in Europe that could potentially be dedicated to the cultivation of non-food crops by 2020 (cited by Perpiña Castillo et al., 2015). In 2012, around 7.4 million hectares of EU agricultural land was recorded as "fallow" in the EU statistics according to the studies of (Allen et al., 2014). In absolute terms over 75% of all fallow land in the EU can be found in just five countries [Spain, (46%), Romania (10%), France (6.8%), Italy (6.4%) and Poland (5.9%)]. The agronomic need for fallow is often greater in arid areas.

Abandoned agricultural land can be due to (i) *transitional abandonment* as a result of restructuring land, political reform, land use change, or economically marginal areas in production terms. Transitionally abandoned land can move in and out of agricultural use depending on market prices for certain commodities. (ii) *semi-abandonment land* is used by farmers but with a very low management level. Associated with very low or zero direct economic returns, semi-abandoned land may be maintained for personal/social reasons e.g. tourism, nature, landscape conservation or simply to maintain a long-term family investment. (iii) *actual abandonment* is not used farmland. Natural succession takes over on abandoned land. Rich and wet soils evolve in forest ecosystems, whereas in poor dry soils (south EU) it can be 'steppe-like' grassland vegetation able to survive many years without any active management, such as mowing and grazing. 'Abandonment is only one of the reasons why the declared area of agricultural land use is decreasing. There is also significant afforestation of agricultural land, steady growth in urban, recreational, and infrastructure areas as well as other changes taking place. There are various causes of actual farmland abandonment in Europe including: geographic, ecological and agronomic factors; demographic and socio-economic drivers; the impact of policy; institutional factors; and, historic circumstances, especially in new Member States. These influences differ between European regions' (cited by Allen et al., 2014). According the study of Allen et al. (2014) in six years between 2000 and 2006, the land released by agriculture (**Released land)** increased of about 700,000 ha in EU. This estimation did not include permanent grasslands.

Marginal land, is an ambiguous term that is commonly used in energy crop papers. This is because there is no formal definition of marginality (Shortall, 2013) and this land type is not included in either land use maps or agriculture statistics. According to Soldatos et al., (2013) the marginality can be classified into six criteria such as biophysical, agronomic, economic, environmental, legal & institutional and social constraints to agriculture (below). A more recent study of Soldatos (2015), shows that the return on the investment in miscanthus, giant reed and switchgrass crops is not economically sufficient to cover farmers' costs and risks in southern Europe, especially when mechanization is not an option because of the adverse biophysical conditions.

Criteria for the definition of land marginality (Soldatos et al., 2013)

- *Biophysical*, unfavorable geographical position, difficult terrain, poor soil, adverse climate factors, water shortage / salinity
- *Agronomic*, high input levels in order to maintain satisfactory yields.
- *Economic*, insufficient returns, more profitable land use opportunities, market inaccessibility
- *Environmental*, use of chemicals, water and iar pollution, environmental protection regulations
- *Legal & institutional*, legal restrictions to cultivation and subsidies, restrictive policies, lack of necessary infrastructure, political / geostrategic issues
- *Social*, minimal job opportunities, small land ownership, lack of required human capital

Medium saline, eroded and **contaminated land** are included in marginal land following the biophysical classification criterium, and can be suitable for bioenergy crops (Perpiña Castillo et al., 2015).

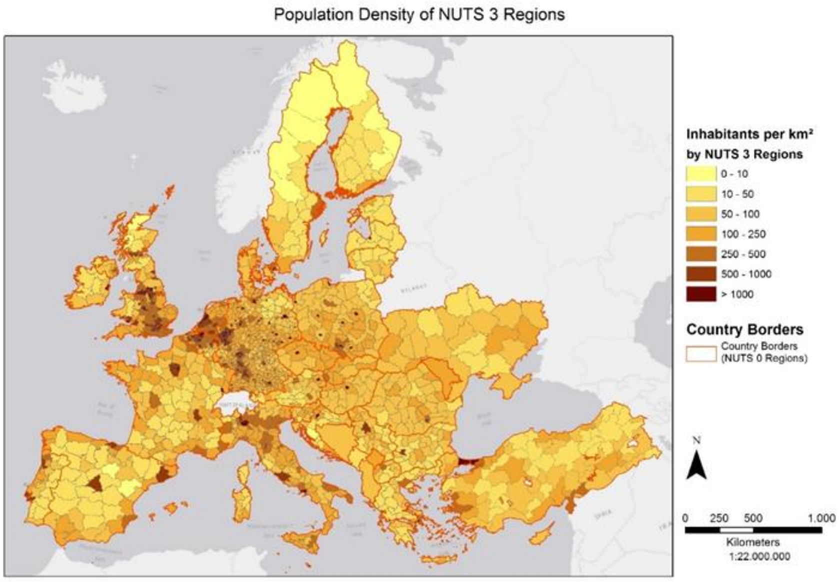
In this study, the land categories used to analise the potential of perennial biomass crops has been selected and divided into two categories of released land from agriculture land: high-quality land, came from good productive lands and low-quality land, include the low-medium productive lands & fallow land.

DATA SOURCES and METHODOLOGY

The study area covers the 28 European member countries (EU-28) and nine central & eastern European countries (Albania, Bosnia & Herzegovina, Montenegro, Republic of Macedonia, Kosovo, Serbia, Turkey, Moldova and Ukraine).

Nomenclature of Territorial Units for Statistics (NUTS), a hierarchical system which divides the European economic territory into economic regions, is categorised in four resolution level as NUTS0, NUTS1, NUTS2, NUTS3 (Eurostat – NUTS 2013 classification), thus, the analysis corresponds to small regions for a specific diagnosis. For instance, the province of Bologna in Italy corresponds to the following: Italia (NUTS0 code: IT), Northeast Italy (NUTS1 code: ITH), Emilia-Romagna (NUTS2 code: ITH5), Bologna (NUTS3 code: ITH55). In this study, resolution level NUTS3 was used, this brings together a total of 1480 NUTS3 codes. In figure 1.1 shows data about European population by NUTS3 (Dees et al., 2017a), which also indicated study area.

Figure 1.1 Population density per Km^2 by NUTS3 level.



Material, data source and methodology used to compile data, are described below in two sections: land availability and land suitability.

Land availability and suitability, main input data used

Data collection are essential to analyse land availability. However, it is difficult to capture spatially all of these areas in Europe because of lack of spatially detailed information and clear definitions. Consequently, those databases consisted of different thematic maps of various spatial resolutions (raster and vector). Thus, collected data was homogenised to the reference frame of the European Terrestrial Reference System 1989 (ETRS89) and Lambert Azimuthal equal area projection. The most important databases are listed below.

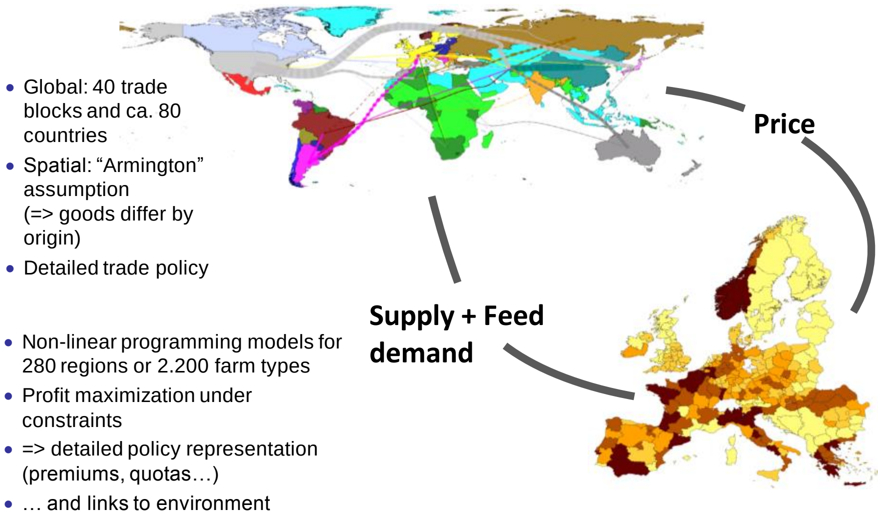
Utilized Agricultural Area (UAA), describes the area used for farming. It includes the following land categories: arable land, permanent grassland, permanent crops and other agricultural land. The UAA data were taken from EUROSTAT and Farm Structure Survey 2010 (FSS) at Nuts3 level (Table 1.1, for more detail see Annex Table A.1)

Table 1.1 Total polygon area and utilised agricultural area. (*Source*: Farm Structure Survey 2010 (FSS) and EUROSTAT for EU-28).

Country	Nuts0 (code)	Total polygon (Mha)	UAA (Mha)	Percent of UAA (%)	Country	Nuts0 (code)	Total polygon (Mha)	UAA (Mha)	Percent of UAA (%)
Turkey	TR	77.21	38.21	49%	Lithuania	LT	6.49	2.74	42%
France	FR	63.80	27.84	44%	Latvia	LV	6.46	1.80	28%
Ukraine	UA	60.11	28.68	48%	Croatia	HR	5.64	1.32	23%
Spain	ES	50.60	23.75	47%	Bosnia & H.	BA	5.12	2.17	42%
Sweden	SE	44.97	3.07	7%	Slovakia	SK	4.90	1.90	39%
Germany	DE	35.75	16.63	47%	Estonia	EE	4.53	0.94	21%
Finland	FI	33.75	2.29	7%	Denmark	DK	4.32	2.65	61%
Poland	PL	31.19	14.45	46%	Netherlands	NL	3.74	1.87	50%
Italy	IT	30.06	12.86	43%	Moldova	MD	3.39	1.94	57%
United Kingdom	UK	24.46	16.88	69%	Belgium	BE	3.07	1.36	44%
Romania	RO	23.84	13.31	56%	Albania	AL	2.88	1.23	43%
Greece	EL	13.20	5.18	39%	R. of Macedonia	MK	2.54	1.26	50%
Bulgaria	BG	11.10	4.48	40%	Slovenia	SI	2.03	0.48	24%
Hungary	HU	9.30	4.69	50%	Montenegro	ME	1.39	0.22	16%
Portugal	PT	9.19	3.67	40%	Kosovo	KS	1.09	0.41	38%
Austria	AT	8.39	2.88	34%	Cyprus	CY	0.925	0.118	13%
Czech Republic	CZ	7.89	3.48	44%	Luxembourg	LU	0.260	0.131	51%
Serbia	RS	7.75	4.89	63%	Malta	MT	0.032	0.011	36%
Ireland	IE	6.99	4.99	71%					

CAPRI model (Common Agricultural Policy Regionalised Impact), determines agricultural demands predicting changes in agricultural sector with a focus on Europe into 280 NUTS2 regions (Britz, 2011), and embedded in a global market model to represent bilateral trade between 40 trade regions (countries aggregates). Thus, CAPRI Model baseline results were further processed to identify the released agricultural land referred to this study as the ‘unused land’ (arable, fallow, pasture and permanent cropping lands not allocated to food and feed production) and their projections for the year 2020 and 2030.

Figure 1.2 CAPRI model components and interactions. *Source*: Elbersen et al., 2017 (in press - S2Biom Book).



CORINE Land cover - CLC2012, is a geographic land cover database for Europe which provides 100-meter pixel raster images at small scales up to 1:800.000 and vectors at higher scales. The main categories of the land cover/ land use are artificial surfaces, agricultural area, forest and semi-natural area, wetlands and water bodies. In the agriculture land category is divided into 4 subclasses: arable land, permanent crops, pastures & heterogeneous agricultural area. Furthermore, were used CLC2012 to analyse the spatial cover of UAA also.

MARS database (Monitoring of agriculture with remote sensing), gridded agro-meteorological data in Europe. The data were collected from MARS-AGRI4CAST resources Portal of European Commission (MARS, 2014). The daily long-term data average, since 1975, used were temperature minimum, average, maximum (°C), rainfall (mm) and reference evapotranspiration - ET_0 (mm), available on grid cells of 25x25 km. http://agri4cast.jrc.ec.europa.eu/DataPortal/Index.aspx

Soil and terrain data, Soil Geographical Database was collected from the European Soil Database version v2.0 at scale 1:1.000.000, produced by European Commission (SGDBE, 2012). The soil features: soil depth and soil texture were taken from Miterra data, no data were available for Western Balkans, Turkey and Moldova. In the same way, the terrain data such as steep slope database at NUTS3 level was taken from Miterra data base (Lesschen et al., 2011; Veldhof et al., 2009).

Sustainability Renewable Energy Directive (***RED) Criteria***, these criteria take into account categories such as: support agro-biodiversity, carbon stock, direct/indirect land cover change, impact on soil quality, water resources and avoid competition with food. The RED Criteria also sets a maximum slope limit for cultivation and requires that only perennial crops can be grown on sites susceptible to soil erosion; that management practices (crop choice and yields) should be adapted to local biophysical conditions, particularly they should not lead to depletion of natural water resources. In addition, they should also enhance agro-biodiversity and lower soil erosion risk which prescribes location where these crops should and should not be grown, what crops choices can best be made and what management practices are required (see Table 1.3).

Protected area, called No-go Area also**.** In RED criteria is include restriction on biomass production in protected areas (national and international), restriction on areas with high biodiversity value (Natura2000 and HNV farmland) and lands with high carbon stock (primary forest and wooded land, wetlands and peatlands). Thus, the following protected areas were excluded:

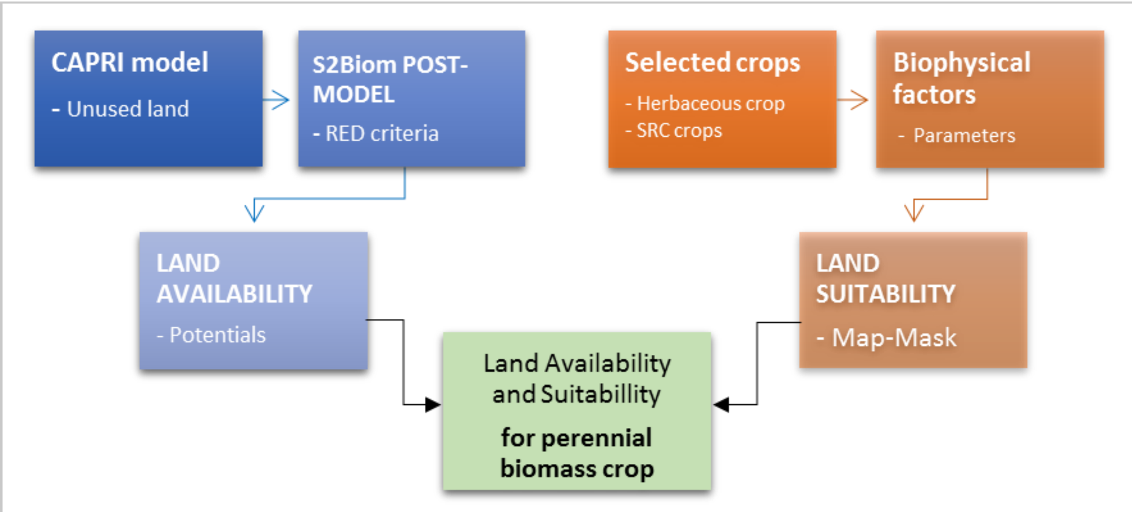
i. *Nature2000*, is a network of core breeding and resting sites for rare and threatened species, and some rare natural habitat types which are protected in their own right. It stretches across all 28 EU countries, both on land and at sea. Cover 18 % of the EU's land area and almost 6 % of its marine territory, it is the largest coordinated network of protected areas in the world. The spatial layers' data is provided by the EEA.
ii. *High Nature Value (HNV) Farmland areas*, is a concept that recognizes the causality between certain types of farming activity and natural values related high levels of biodiversity and/or the presence of species and habitats of conservation. This spatial database is available and can be used as an EU wide database for the farmland areas of high biodiversity (ETC/SIA, 2013). No data were available for western Balkans, Croatia, Moldova and Ukraine.
iii. *Permanent grassland habitat*, are often characterised by high biodiversity value in terms of the species richness and vegetative structure that is the reason to many grassland-habitats are included in the High Nature Value farmland (HNV). In CLC2012 code n.18.

For Non-EU countries as Ukraine & Moldova are not covered by CAPRI. Land availability was determined by using the national agricultural statistics that register 'unused farmlands' and fallow lands as a separate category. The 2012 data were kept constant towards 2020 & 2030.

Overall approach to identifying land availability and suitability

In **Figure 1.3** shows an overview of analysis steps to identify land availabillity and land suitable for perennial biomass crop taken account in the follow sections.

Figure 1.3 Integration of CAPRI land availability with land suitability for herbaceous and SRC crops



METHODOLOGY: to identify UNUSED LAND POTENTIAL (LAND AVAILABILITY POTENTIALS)

Land-potential is defined as the inherent potential of the land to sustainably generate ecosystem services (www.landpotential.org). This section present the methodology applied to calculate potential unused land amount from agriculture, and which could be available for the cultivation of perennial biomass crop.

In this study, the unused land has been estimated using output of the CAPRI model as input in a further post-model assessment. The CAPRI model predicts the future market and production responses at the regional level for the whole EU-28, western Balkans, Turkey and Norway. It is therefore the only source of information available that gives a plausible overview taking account of the specific diverse regional circumstances, of what land-use changes can be expected by 2020 and 2030. The CAPRI baseline assumes compliance with EU policy regarding bioenergy targets based on the PRIMES energy model as reported in the *Trends to 2050 report* (Capros et al., 2013), including its effects on agriculture. The emphasis in the CAPRI baseline has been on the food, feed and biofuel crops given 2020 and 2030 renewable energy targets at the national level and it provides detailed information on agricultural land-use cropping and livestock patterns at regional (NUTS2) level.

CAPRI model results still need further POST-MODEL analysis to derive the maximum land availability for dedicated cropping from it. The reason is that the demand for lignocellulosic biomass from new biobased economy sectors has so far not been fully internalised into CAPRI. Therefore, the CAPRI baseline results that do allocate some lignocellulosic cropping area for a limited amount of second generation (2G) biofuels, do not reflect a full use of the land potential in Europe given a much wider demand for lignocellulosic biomass from all bioenergy sectors (including bio heat, electricity, chemicals and materials). This implies that in a post-model approach the CAPRI model output had to be processed further to identify the full land availability for dedicated crops.

Three types of lands with potential for biomass crops can be extracted from the results of the capri model (land not required to satisfy the feed and food demand according to CAPRI).

(i) Unused land, which is land that was in agricultural use in 2008, but not in 2020 and 2030

(ii) Land that is left fallow in 2020 and 2030 according to the CAPRI baseline.

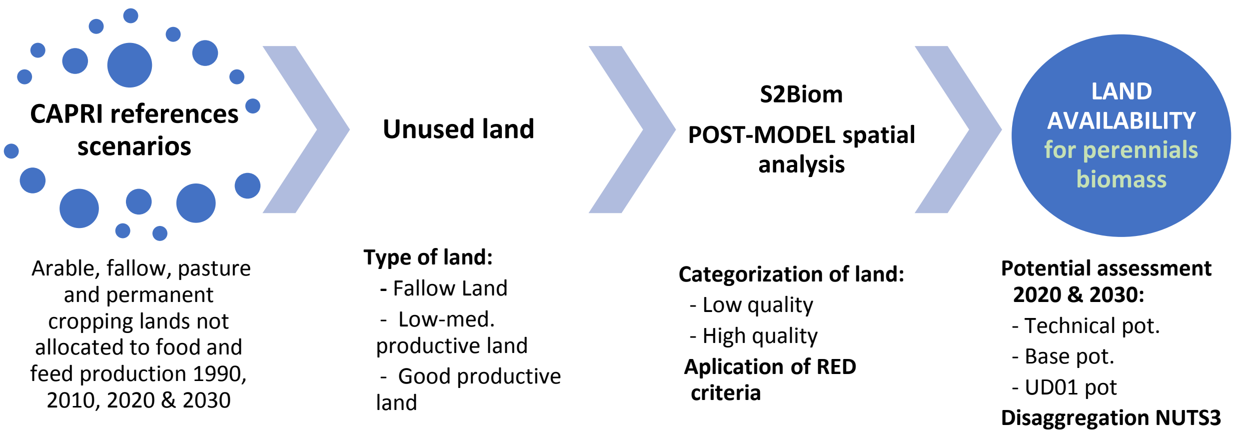
(iii) Land already dedicated to new energy crops (NECR) according to the amount of advanced biofuels that are expected to be based on dedicated lignocellulosic crops as exogenously assessed with the PRIMES model (see above). These NECR lands are consistent with the demand for food, feed and 1G biofuel crop demands according to CAPRI.

Thus, the identification of the unused land requires the elaboration of a land use balance approach comparing the land use situation in 2008 from CAPRI against the in 2020 and 2030. To identify the following post-model analysis steps were performed:

- It was determined how much land in the arable land category is used in 2008 as compared to 2020 and 2030. If this land is larger in 2020 or 2030 there is no land released in this category and the land increase will need to come from losses in lands in the other land use categories, e.g. permanent grasslands and crops. If there is less land used we assume that there is a land release, which first needs to be (partly) absorbed for increases in permanent crops and permanent grassland categories. After this and there is still released land left it may be counted as part of the land potential for dedicated biomass crops.

- Then the land used in the permanent crop and the grassland categories for 2008 is compared with these lands in 2020 and 2030. Again, it can be determining whether land is released or whether it has increased within these categories. If there are land releases they should first be used to absorb possible land use increases in the other categories, the remaining is potential for biomass crops.
- Next the net land releases or increases are combined and if resulting in a net decline in agriculturally used land in 2020 and 2030 it can be regarded as ‘unused’ by agriculture so far and thus potentially available for (additional) dedicated biomass cropping. In addition, fallow land and the land already used for new energy crops can be added to this resource.
- The net land releases are distributed in two types of land: high and medium to low quality lands. It is assumed that if there is net land release in the arable or orchard category this land is allocated to the *high-quality* group. Releases from olive groves, vineyards and permanent grassland are allocated to the medium to the *low-quality* group. Fallow land is assumed to be medium to *low-quality*. The land already allocated in CAPRI to NECR, given advanced biofuel target shares is distributed 50% over good and 50% over medium to low quality.

Figure 1.4 Methodology used to estimate land availability for lignocellulosic biomass crop a NUTS3 level.



Therefore, the agriculture released land were divided according to three type of land (Figure 1.4): released *good productive lands* (e.g. used for rotational crops, fruit crops and temporary grassland), released *low-medium productive lands* (came from lower productive lands - used for other permanent crops e.g. vineyards, olives, nuts etc. and permanent grasslands) and *fallow land* (details of land definition in Table 1.2).

Table 1.2 Types of unused lands (*Source:* Biomass Policies project, Elbersen et al., 2015).

Type of land	Description	How to identify from statistical sources or through modelling
Fallow land	In FSS Eurostat (Council Regulation 543/2009) the definition of Fallow land (short term) *is all arable land included in the crop rotation system, whether worked or not, but with no intention to produce a harvest for the duration of the crop year. The essential characteristic of fallow land is that it is left to recover normally for the whole crop year.* Fallow land can be either bare land bearing no crops at all; land with spontaneous natural growth which may be used as feed or ploughed in; land sown exclusively for the production of green manure (green fallow).	In FSS, FADN, LPIS and national agricultural statistical land use sources (see next section on main data sources) the land category 'fallow' is registered as a separate category.
	Long term fallow land refers to the same land as above, but is taken out of production for more consecutive years	CAPRI model
Abandoned agricultural lands	This category of land does not have any productive agricultural use any more and is no longer managed in any way.	This category of land is not registered in statistics and there is no public obligation to register it in any database. Identifying this type of land is challenging as and no systematic registration of this land exists. However, an identification of recently abandoned grassland areas was made using LUCAS point information and main text.
Other unused and/or contaminated lands	This category may cover a wide range of land categories with one common characteristics and this is that these are unused. An interesting land category in this group is the contaminated land. Dedicated perennials may be grown here to produce non-food biomass while helping to clean the land via (phytoremediation).	Through existing land use statistics these categories of land are difficult to identify. For contaminated lands, there is information collected by the JRC European Soil Data Centre (ESDAC, 2011) but this database is incomplete (see Allen et al., 2014).

In S2Biom POST-MODEL to calculate the land availability for perennials biomass, three type of land has been divided into two categories of land: high-quality land, came from good productive lands and low-quality land, include the low-medium productive lands & fallow land. Then, potential land assessment has been calculated to the year 2020 & 2030.

Three potentials were used: Technical potential, Base potential & Strict suitability Potential (UD01). The Table 1.3 present rules implemented on criteria categories to assess land availability (Dees et al., 2017a).

Firstly, *Technical Potential*, is determined by S2Biom POST-MODEL as a baseline. Categorised in low and high quality of land for the year 2012, 2020 & 2030.

Secondly, *Base Potential* was obtained from baseline result of technical potential and application of RED criteria rules (Table 1.3). To take account of the RED rules, was imperative to estimate the percentage of area that should be excluded of technical potential. Therefore, the combination of layers used were: utilized agricultural area (UAA), CLC2012 (excluding the permanent grassland -

Code n.18), Nature2000 (in/out agricultural area), HNV (percentage greater than 50% is excluded), steep slope (percentage greater than 15% is excluded). For every grid were include/exclude the combination and counting number of cells in hectare (100m x 100 m) for every NUTS3. After calculating the amount of land to be excluded in each NUTS3, it was divided exclude zones with the total agricultural area (UAA) at NUTS3 level, resulting a percentage of land exclusion according to RED criteria for Base potential. This same percentage (%) was applied to the result of technical potential as factor reduction. This is all assuming that the total percentage of land excluded at the NUTS3 level could be the percentage of land to be excluded from the results of technical potential, thus giving as a Base potential result.

Table 1.3 Sustainability Renewable Energy Directive (RED) criteria for assessing land available for dedicated biomass crops considered in each potential (Source: Dees et al., 2017a).

RED criteria	Rules implemented	Technical potential	Base potential	User defined potential
No loss of habitat of high biodiversity value	Exclusion of use of Natura2000 areas & other protected areas		X	X
	Exclusion of use of High Nature Value farmland		X	X
No use of areas of high carbon stock lands	Exclusion of wetlands & peatland areas		X	X
	Only use lands that have been registered as agricultural since 1990 which ensures exclusion of contineous forest lands	X	X	X
	Exclusion of permanent grasslands (even if released from agriculture as assessed by CAPRI)		X	X
Avoidance of direct land cover changes	Only use lands that have been registered as agricultural since 1990 and marginal and polluted lands (as identified y JRC). This ensures exclusion of contineous forest lands, urban lands, recreational areas etc.	X	X	X
	Avoid conversion of permanent grasslands to arable		X	X
Avoidance of indirect land use changes	Only use surplus (agricultural) lands and marginal and polluted lands	X	X	X
Support agro-biodiversity	Avoid use of Natura2000 & HNV farmland (even if released from agriculture as assessed by CAPRI)		X	X
	Avoid conversion of permanent grasslands to arable		X	X
	No use of fallow land if fallow land share (in total arable land) declines to < 10%			X
	Avoid monoculture choosing mix of at least 3 perennial crops per region (covering both SRC and herbaceous crops)		X	X
Avoid negative impacts on soil quality & enhance soil quality impacts	Maximum slope limits to perennial plantations		X	X
	Use perennial plantations to protect soil susceptible to erosion		X	X
	Use perennial plantations for bio-remediation of polluted soils			
Avoid negative impacts on water resources	Only use crops where minimal water requirement is delivered through annual precipitation (so irrigation is allowed but water depletion is avoided)		X	X
	No use of irrigation in perennial crops			X
	Preference for water use efficient crops in drought prone regions			X
Avoid competition with food	Only use surplus (agricultural) lands	X	X	X

* Where “X” means the application of rule for potentials type.

Thirdly, Strict sustainability Potential (UD01). It was obtained from the result of Base potential and strict application of RED criteria rules (Table 1.3). Then, for this potential calculation was uses the factor of reduction result from Base potential (%), and RED criteria. The latter, RED criteria, has included two more rules as *Avoid negative impacts on water resources* and *Support agro-biodiversity*. Only rain-fed crop production is allowed. Crops that need irrigation in arid regions cannot be used. Furthermore, the land was classified no available when the fallow land amount was less than 10% respect to arable land at NUTS3 level.

Last step, due the land data share determined by CAPRI model include lower resolution level NUTS2, a conversion was necessary in order to obtain more specific data at a resolution level required in this study, so the data were proportionally disaggregated from NUTS2 to NUTS3 code.

In the calculation of the Land Availability some assumptions were made due to the lack of data for Ukraine and Moldova, for instance, CAPRI model not includes these countries, reason why the value does not change to the year 2020 & 2030 (data available only for the first scenario). Thus, for was collected data available, but these were not categorized, then it was assumed that 25% was released land of good quality and 75 % released land of low quality & fallow.

LAND SUITABILITY

Land suitability refers to land with no or low suitability for one or more types of perennial biomass crops. In the two-steps above the land availability is limited by specific environmental factors from the RED. In addition, it will also be necessary to determine which crops are suitable per type of land, particularly given the strong overlap with marginal conditions abandoned agricultural lands are likely to have. To address this suitability maps were prepared masking (part of) the regions that are not suitable for specific crops because of climatic and or bio-physical limitations.

Agroclimatic database

Data collection of agronomic requirement for each crop are essential to analyse land suitability. Selected crop are five herbaceous perennials (miscanthus, switchgrass, giant reed, cardoon, reed canarygrass) and three SRC: willow, poplar, eucalyptus).

The suitability masks for crops were elaborated in two steps:

- Firstly, it was identified which climatic and biophysical factors were relevant to identify the spatial suitability ranges for the different perennial crops in Europe. Since the focus is on lands that are not used/no longer to be used for food and feed production, the lands will often be of lower quality often overlapping with characteristics that classify lands as 'marginal'.

- Secondly, per crop specific threshold levels were identified based on information obtained from a literature review.

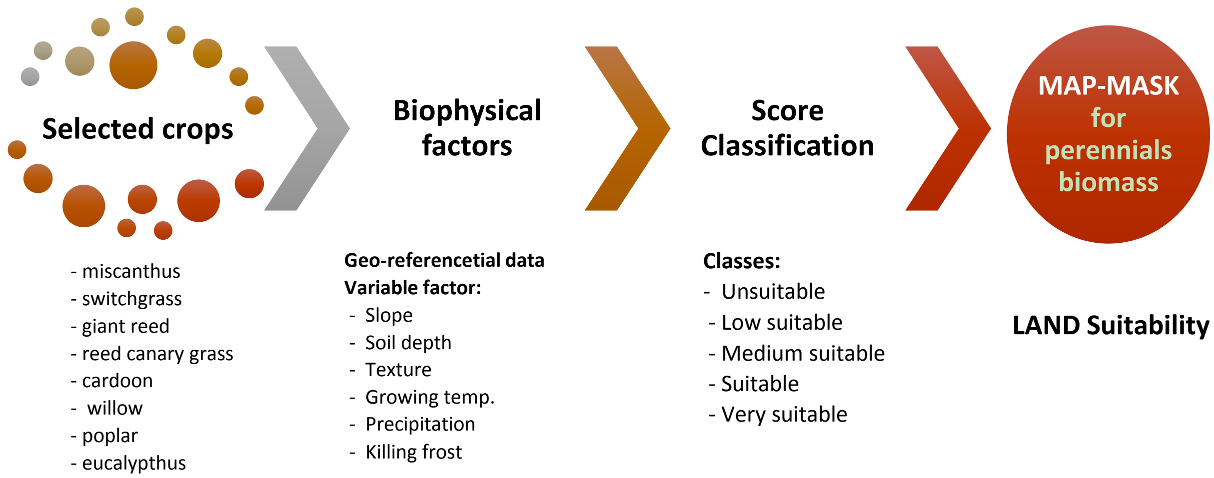
Details on how these 2 steps were implemented are discussed in the following.

METHODOLOGY: to identify LAND SUITABILITY

The aim is to create maps-masks, which indicate the suitable and unsuitable land for each crop. However, to identify the area suitable according to the characteristics and requirement of the crop, it is not a simple procedure. Thus, the methodology in this section answers only a question, is it possible to grow this perennial crop? (for each Crop/ NUTS3 code). If the answer is No, the NUTS3 code is automatically excluded.

This process was carried out for each of the eight perennial biomass crops and the 1480 NUTS3 codes, and the procedure are showed in Figure 1.5. Of the seven variables shown in Table 1.6, pH was not included because of lack of spatially-detailed information and clear definitions (NUTS2 avg.).

Figure 1.5 Methodology used to estimate land suitability for selected lignocellulosic biomass crop a NUTS3 level.



Biophysical contraints - database

Relevant studies present main categories of biophysical constraints which are climate, soil and terrain (Terres et al., 2014; Perpiña Castillo et al., 2015). In Table 1.4 shows the most important biophysical variables and the references where is possible find data for perennials biomass crops. Agro-meteorological data (MARS, 2014), soil geographical database (SGDB) and slope data was used (see description in Land availability datasource).

For assessing the suitability of land, we identified which requirements every crop has in relation to geomorphological, soil and climatic variables. The main aspects identified were temperature (length of growing season & GDD), killing frost, precipitation, texture, depth soil, steep slope.

Table 1.4 Variables considered in the spatial suitability maps.

VARIABLES	DESCRIPTION	References for crop variables
Steep slope	Divided into five classes: <4%, 4-8%, 8-15%, 15-25% and >25%. Slopes more than 15% can be difficult for harvest machinery. Data available from Miterra.	Perpiña Castillo, C. et al. (2015); Eliasson et al. (2010); EU-JRC, (2013); Allen et al. (2014)
Soil depth	Important for the root development that was divided into four classes.	Perpiña Castillo, C. et al. (2015)
Texture	Defined in five classes, taken from Miterra data.	Perpiña Castillo, C. et al. (2015)
Soil pH	Classes from <4 to >9, soil pH exceeding these extremes is considered not favourable for crop growth.	Perpiña Castillo, C. et al. (2015) Bassam, (2013); Duke James A. (1983)
Temperature	Divided according to the data review. The data was provided in grid cells 25 x 25 km. from MARS data.	Biomass future Project (2010); 4fcrop Project (2011); (Basssam, 2010)
Precipitacion	Average annual precipitation in mm. was divided into six classes. The data was provided in grid cells 25 x 25 km. from MARS data.	Zegada-Lizarazu et al. (2010); Nsanganwimana F. et al. (2014); AUST et al. (2014); Fernandez J. (2009); Zegada-Lizarazu and Monti (2012); Alexopoulou et al. (2015); Perpiña Castillo, C. et al. (2015)
Killing frost	Divided into five classes. These are the minimum temperature of the plant. The data for each crop were taken of bibliography review, how is the resistance to minimum frozen of the crop.	Hopp et al. (1990); Bassam, (2013); Angelini et al. (2009); Zub & Brancourt-Hulmel (2010); Lewandowski et al. (2003); Fernandez J. et al. (2006)

In Table 1.5 first an overview is given of the key crop requirements and tolerance ranges they have in relation to main climatic aspects. This takes into consideration photosynthetic system, adaptation range in EU, tolerance to dry conditions, water request, growing temperature minimum & maximum (C°), water requeriment (mm) and killing frost (C°).

Table 1.5 Crop requirements given phenological characteristics

Crop	*Photosynthetic System*	*Adaptation range in EU*	*Tolerance to dry conditions*	*water request*	*Growing temp. maximum (°C)*	*Growing temp. min (°C)*	*water requirement (mm)*	*Killing frost (°C) Winter (>5 days)*
miscanthus	*C4*	Cold and warm	High	*High*	40	10	*>500*	-10
switchgrass	*C4*	Cold and warm	High	*Medium*	35	10	*450 - 750*	-20
giant reed	*C3*	Warm region of southern EU	High	*Low*	35	5	*380 - 650*	0
reed canary g.	*C3*	Cold and wet regions of EU	Medium	*High*	30	7	*400 - 900*	-30
cardoon	*C3*	Mediterranean region	High	*Low*	35	5	*300 - 400*	0
willow	*C3*	North EU	Low	*High*	30	0	*>620*	-30
poplar	*C3*	Central and south EU	Medium	*Medium*	30	0	*>600*	-30
eucalyptus	*C3*	South EU	Medium	*Medium*	35	5	*>500*	0

Source: Alexopoulou et al. (2010); Bassam, (2010); EEA, (2007); Zegada-Lizarazu et al. (2010); Lewandowski et al. (2003); Fernandez et al. (2006); Fernandez and Curt, (2005); Elbersen et al. (2012)

The next step after defining the variables to be considered was to determine the specific threshold values per crop in relation to environmental factors. This was done through a literature review which is presented in Table 1.6 (data references in Table 1.4) and expert's consultation. The summary in Table 1.6 shows the different biophysical factors and the score obtained on the basis of the crop.

Assumption, in this study, was defined the 'marginal land' as the land low quality, steep slope, adverse climate, water shortage, Agronomic (low input) and environmental. Scores at level NS or LS are in the 'marginality range' according to Van Oorschoven et al., (2012) and Terres et al., (2014). Thus, the georeferenced data collected (climatic and soil characteristics) and the variables-score was translated in algorithms (in GAMS programming language) and combined. The georeferenced data was divided in 4 to 6 classes (according to the Table 1.6), defined on number scores value (0,1,2,3,4) by crop.

Formula used:

$$\text{Suitability}_{\text{Total score (NUTS3, crop)}} = \text{slope} + \text{soil depth} + \text{texture} + \text{killing frost} + \text{precipitation} + \text{temp}_{\text{max}}$$

$$\text{Suitability}_{\text{Total score}} = \Sigma_{\text{factor (nuts3, crop)}}$$

The following rules were applied to determine the land suitability, for the <u>climatic side</u>, when the value Killing frost, precipitation, and maximum temperature was '0' the final score was automatically unsuitable. For the plant with the highest request of water as willow, poplar and RCG, a stricter measure was imposed with respect to the precipitation limit. Therefore, when in the growing period the rainfall estimates are lower than the plant needs (insufficient precipitation based on the literature), NUTS3 code was automatically excluded. (applied in all input management level – Chapter 2). In the <u>soil and terrain side</u>, the data were in fraction value for every NUTS3, for instance, in case the slope was greater than 15% that area was automatically unsuitable. For <u>depth</u>

soil in SRC crops, some restrictions were made, when the value is less than 80 cm. It is unsuitable for the development of SRC crop and therefore is automatically excluded.

Table 1.6 Biophysical limiting factors for perennial biomass crop

Variables – Classes	miscan.	switch.	RCG	giant reed	cardoon	willow	poplar	Eucalyp.
Slope (%)								
<4 %	VS	VS	VS	VS	VS	VS	VS	VS
4-8	S	S	S	S	S	S	S	S
8-15	MS	MS	MS	MS	MS	MS	MS	MS
15-25	LS	LS	LS	LS	LS	LS	LS	LS
>25 %	NS	NS	NS	NS	NS	NS	NS	NS
Soil depth (cm)								
Shallow *(< 40 cm)*	NS	NS	NS	NS	NS	NS	NS	NS
Moderate *(40 - 80 cm)*	LS	LS	LS	LS	LS	LS	LS	LS
Deep *(80 - 120 cm)*	MS	MS	S	MS	MS	MS	MS	MS
Very Deep *(> 120 cm)*	VS	VS	VS	VS	VS	VS	VS	VS
Texture								
Sand *(coarse)*	MS	MS	LS	MS	MS	MS	LS	LS
Loam *(medium-medium fine)*	VS	VS	VS	VS	VS	VS	VS	VS
Clay *(fine)*	MS	MS	MS	S	MS	MS	MS	MS
Heavy clay *(very fine)*	LS	NS	LS	MS	NS	NS	NS	MS
Peat *(no mineral texture)*	NS	NS	NS	NS	NS	NS	NS	NS
Soil pH								
<4	NS	NS	NS	NS	NS	NS	NS	NS
4-5	LS	LS	LS	LS	NS	LS	LS	LS
5-6	S	MS	S	MS	MS	MS	MS	MS
6-7	VS	VS	VS	VS	VS	VS	VS	VS
7-8	MS	MS	MS	MS	S	S	S	S
Growing Temp. (°C) GS								
<5	NS	NS	NS	NS	NS	NS	NS	NS
5-8	LS	LS	LS	NS	NS	LS	LS	NS
8-10	MS	MS	MS	LS	LS	MS	MS	LS
10-20	VS	VS	VS	S	S	VS	VS	S
20-30	S	S	MS	VS	VS	MS	MS	VS
>30	LS	LS	NS	MS	MS	NS	NS	MS
Precipitacion (mm)								
< 300	NS	NS	NS	NS	NS	NS	NS	NS
300 - 400	NS	NS	NS	NS	LS	NS	NS	NS
400 - 500	NS	LS	NS	LS	MS	NS	NS	NS
500 - 600	MS	MS	NS	MS	S	NS	NS	LS
600 - 800	S	S	MS	S	S	MS	MS	MS
800 - 1000	S	VS	S	VS	VS	S	S	S
Killing frost (°C)								
>-20	NS	NS	MS	NS	NS	MS	MS	NS
-20	NS	MS	MS	NS	NS	MS	MS	NS
-10	MS	MS	MS	NS	NS	MS	MS	NS
-5	MS	MS	S	MS	MS	S	S	MS
0	S	S	S	S	S	S	S	S

**Note*: The scoring on the different bio-physical factors is classified as follows: "0" unsuitable (NS), "1" Low suitability (LS), "2" medium suitable (MS), "3" suitable (S),"4" very suitable (VS).

Thus, the result was a Table 1.6, where the score value ‘0’ implies ‘not suitable was excluded. The other value scores greater than zero ‘0’ were considered as land suitability potential for the perennials biomass crop. With this methodology, it was possible to build a base procedure to analyse land suitability, where specific suitability map-mask at NUTS3 level was generated considering the biophysical factors constraints for each crop.

Overall crop specific requirements show that all perennials and SRCs types can generally grow on steeper slopes than the slope level rotational arable crops can cope with (slope <8% are the most suitable for crop development, but, slopes more than 15% can be a problem to harvesting machinery). This is related to denser soil cover and deeper rooting and lower (mechanisation) input requirements lowering the risk for soil erosion. Furthermore, many perennials can even be used to prevent erosion. Low precipitation/dryness is another factor many perennials can cope well with. This is particularly the case for cardoon and also switchgrass and giant reed. Of course, this also goes together with lower yields, but these crops are still able to survive with very low precipitation levels, while this would certainly not be the case for most if not all rotational arable crops. SRC willow and poplar are however more sensitive to limited water availability. They actually have a preference for relatively wet soils which are not well drained, so these crops even do better under these marginal circumstances many other crops cannot cope with. On the other hand, if the water-holding capacity of the soil is bad and there is low precipitation (<500 mm) SRC willow and poplar crops cannot be grown there.

Some perennials can also cope with very heavy clay, which is particularly the case for giant reed, RCG and eucalyptus SRC. Acidity is also less of a problem for all perennials as compared to most rotational arable crops. However, soils too shallow is a challenge for all perennials because of their deep rooting requirements.

For killing frost a distinction was made between winter frost (when the plant is dormant) and spring frost, when the growing season has started. Frost occurrence in this early growth stage can be particularly harmful for some crops (see Table 1.5) such as cardoon, giant reed and eucalyptus limiting the area in Europe they can grow significantly as compared to switchgrass and also miscanthus. The latter crop is however not able to cope with too extreme winter colds as it limits strongly the survival rate and prevent enough re-growth in spring. This explains a slightly smaller area suitability coverage for miscanthus as compared to switchgrass or willow.

The temperature range indicator in Table 1.5 shows the minimum and maximum temperatures a crop has to cope with in the growing season. A small difference in temperature such as in typical the Boreal and Alpine north zones of northern Europe where growing seasons are very short and temperatures usually do not come far above 10 °C. In these regions, it is not really worthwhile to grow biomass crops as yields will remain very low and most of the perennials cannot reach their minimal growing degree days to deliver good quality biomass.

Results

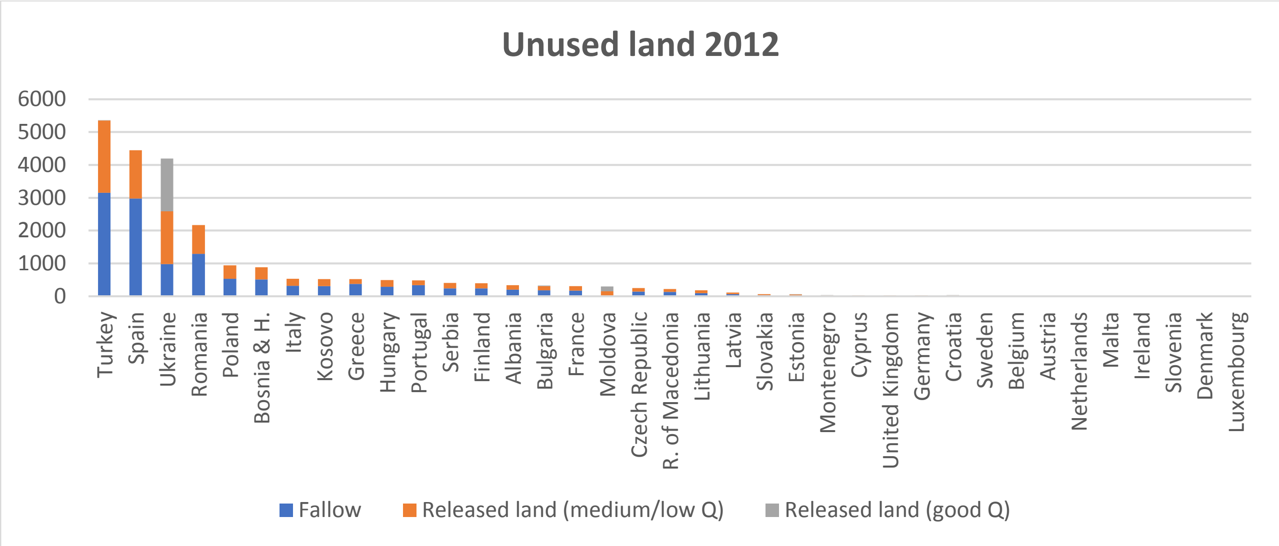
Unused Land from CAPRI

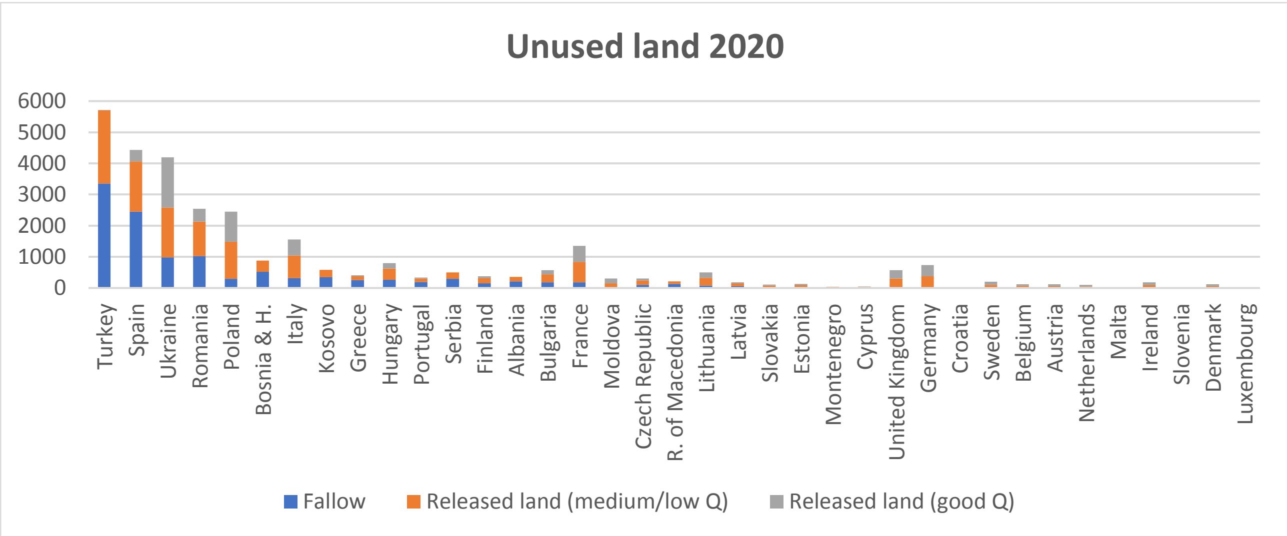
Land types as low-medium productive land, good productive land and fallow land (see Figure 1.4) are shown in Figure 1.6. The situation in 2012 of unused land amount was about 23.7 Mha for the 37 countries, where the dominant land types 54% came from Fallow land, 39% released land (low-medium productive land) and 7% released land categorised as good productive. The countries with the largest unused land potential are Turkey (5.3 Mha), Spain (4.4 Mha), Ukraine (4.19 Mha), Romania (2.17 Mha) and Poland (0.9 Mha), which would correspond of their agricultural area in 13.9%, 18.5%, 14.6%, 16.3% and 6.2% respectively, in base to UAA-2012.

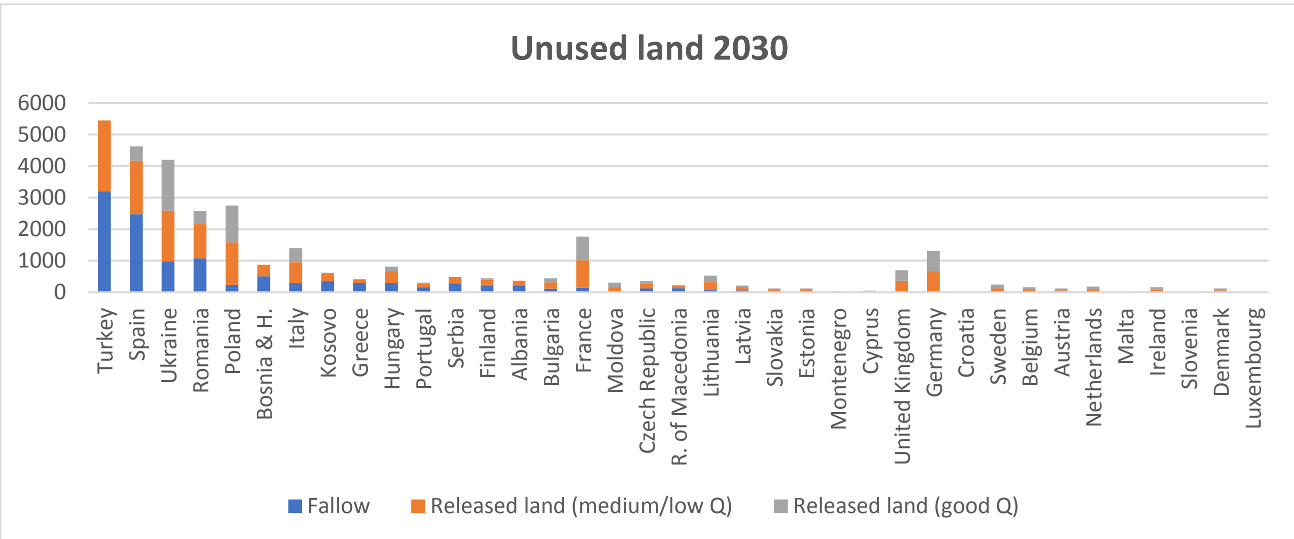
According to the CAPRI model and post-modelling approach, the situation for 2020 and 2030 predicts an increase in un used land covering 31 Mha and 32.4 Mha, respectively. What would be in terms of dimension an area similar to Poland or Italy. And where most unused land comes from released land. For example, until 2030 the model predicted that 35% would come from fallow land, 43% to the released land (low-medium productive land) and 22% released land (good productive land). Therefore, the countries most likely to increase their land not used to 2030 are Spain, Romania, Poland, France, Italy, Hungary and UK.

Since CAPRI did not simulate land and market changes for Ukraine a simplified method was applied to determine the land availability. The main data input was from the national agricultural census. This census registered the amount of agricultural land, the fallow land and the land not used for production purposes. These 2 categories of land were assumed to be available for dedicated cropping since they were not used to satisfy food and feed production given current market forces. Since no future assessments were available for land needs for food and feed production the simple assumption was made that the land resource available in 2012 would remain stable towards 2020 and 2030.

Figure 1.6. Unused land in agricultural areas from CAPRI to the year 2012, 2020 & 2030 (Unit: 1000 ha.)







Land Availability Potentials

The released land potentials resulting from the CAPRI post-model assessment had to be translated into a land availability in the three different potential options. For their quantification, the criteria were applied as presented in Table 1.3 above. In order to facilitate the understanding and discussion, the results of the 37 countries were divided into EU28 (European member countries) and Non-EU (Albania, Bosnia and Herzegovina, Montenegro, Republic of Macedonia, Kosovo, Serbia, Turkey, Moldova and Ukraine).

Technical Potential resulting to the year 2012 for EU28, indicate the country with the highest concentration of unused land is Spain about 4.4 Mha, followed by Romania with 2.17 Mha. Projections for 2020 indicate for EU28-2020 will present in total unused land 18.3 Mha, where about 75% (13.7 Mha) correspond as *low-quality land*. For Non-EU-2020 countries in total have 12.8 Mha where about 86% (11 Mha) derive from for *low-quality land*. Projections for 2030, show in EU28-2030 results, a slight increase to total 19.9 Mha of unused land (low and high-quality land) (see Table 1.7). In the case of Non-EU-2030, there is also a slight increase (0.3 Mha) compared to the previous projection 2020. This reduced margin can be due to the lack of data for Ukraine and Moldavia in the CAPRI model, but it could also suggest that a land of good character is still cultivated.

Base potential resulting present a decrease of land respect to technical potential, obviously due to the application of RED-criteria rules, where protected areas were excluded (see Table 1.7). Protection for 2020 the countries of EU28 shows a high amount of unused land, about 13.8 Mha where 73 % (10.1 Mha) is occupied for *low-quality land*. Therefore, into category *Low-quality land*, the largest potential unused land in EU28 was found in Spain with 2.68 Mha, followed by Romania 1.54 Mha and Poland 1.18 Mha, which would correspond to a reduction of their agricultural area in 11.2%, 11.5% and 8.1% respectively, in base to UAA (see Table 1.1). In other hand, in Non-EU-2020 cases, the largest potential unused land of *low-quality* category is, in Turkey with 2.8 Mha, followed by Ukraine 1.3 Mha and Bosnia & Herzegovina with 0.4 Mha, which would correspond to a reduction of their agricultural area in 7.3%, 4.5% and 18.7% respectively, in base to the UAA (see Table 1.1). The projection for 2030 in EU28-2030 indicates the countries with the largest amount of unused land remain in the *low-quality* category (Spain, Romania and Poland) with respect to the projections for 2020. They also show that countries such as France (0.86 Mha) and Italy (0.7 Mha) could be prone to leaving large cultivated land. In *high-quality land* category, the countries with the largest share for EU28-2030 are Poland (0.9 Mha), France (0.64 Mha), Germany (0.54 Mha), Italy (0.33 Mha) and United Kingdom (0.32 Mha). For Non-EU-2030, in low-quality land indicates a slight decrease in the unused area, while for high-quality land only values for Ukraine, Moldova, Turkey, and Kosovo are shown but these are not particularly representative (for more detail see Annex A.1).

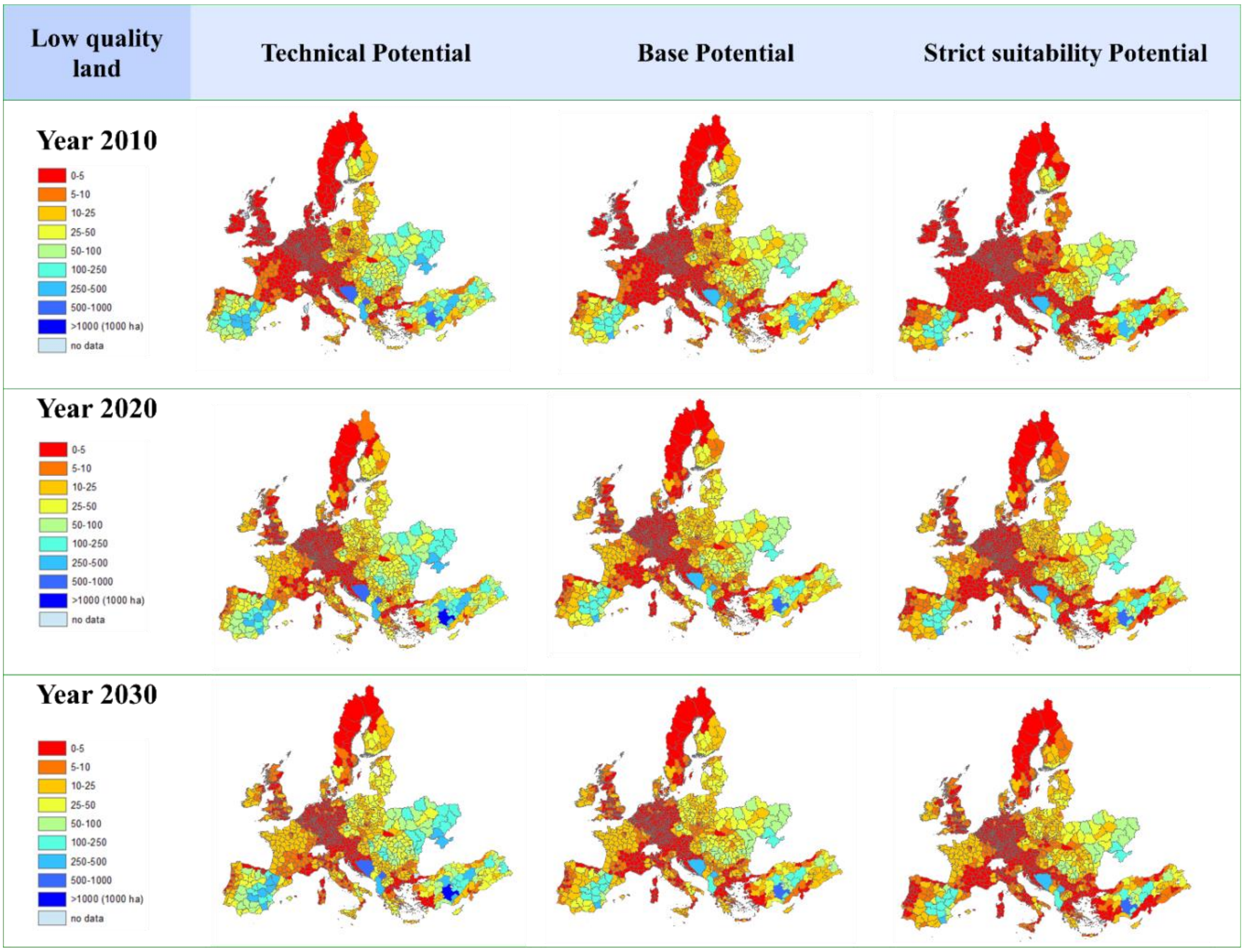
Table 1.7 Unused land in technical, base and strict suitability potential to low and high quality land categories for the year 2012, 2020 & 2030 (Unit: Million ha).

	Technical potential		**Base potential**		**Strict Suitability Pot.**	
Million ha	**Low Q.**	**High Q.**	**Low Q.**	**High Q.**	**Low Q.**	**High Q.**
2012						
EU28	11.5	0.02	8.1	0.01	5.8	0.01
Non-EU*	10.5	1.8	5.2	0.9	4.6	0.9
Total 2012	23.7		14.3		11.4	
2020						
EU28	13.7	4.6	10.1	3.7	8.0	3.7
Non-EU*	11.0	1.8	5.5	0.9	4.9	0.9
Total 2020	31.1		20.2		17.4	
2030						
EU28	14.5	5.5	10.8	4.4	8.7	4.4
Non-EU*	10.7	1.8	5.4	0.9	4.8	0.9
Total 2030	32.4		21.5		18.8	

* Ukraine & Moldova are not covered by CAPRI. Land availability was determined by using the national agricultural statistics that register 'unused farmlands' and fallow lands as a separate category. The 2012 data were kept constant towards 2020 & 2030.

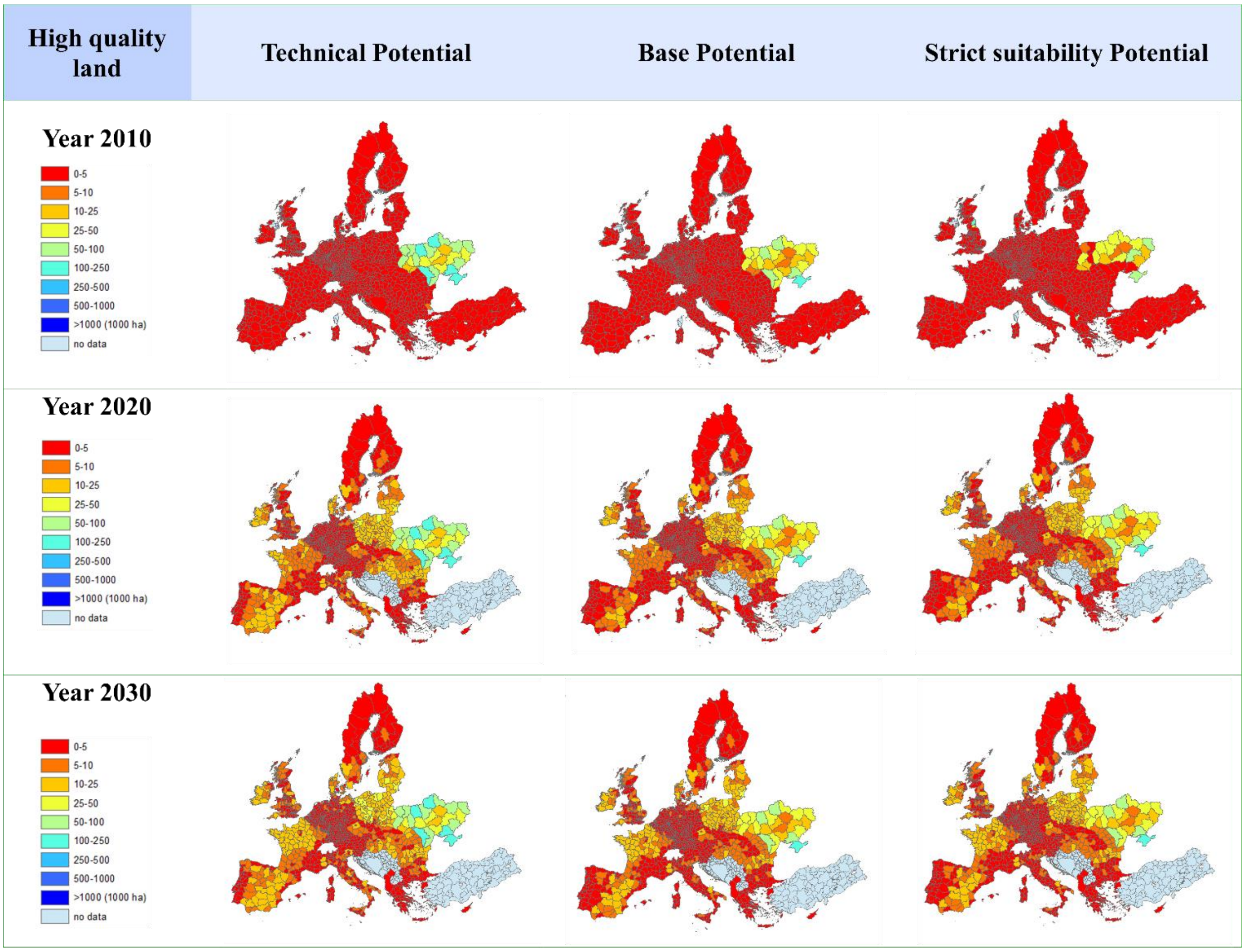
Strict sustainability Potential (UD01) in this potential were applied strict rules according to the RED-Criteria rules, thus, NUTS3 code with a fallow land area less than 10% with respect to the arable area, was excluded from the calculation as potential land for Perennial biomass crop agriculture (see Table 1.7). The projection for 2030 indicates for EU28-2030 a high amount of total unused land, low-quality land about 8.7 Mha and high-quality land about 4.4 Mha. The results show a decrease, due to the exclusion of land according to the rules of sustainability considered with respect to the base potential, thus, countries like Hungary, Malta, Portugal, Czech Republic, Latvia (decreasing order), show a greater reduction of area. This means that in some NUTS3 code, the fallow land was less than 10% of arable land. For Non-EU-2030 of total unused land, low-quality land about 4.8 Mha and high-quality land about 0.9 Mha. Finally, it is concluded that the total of unused land (low and high-quality land) according to the most stringent potential in EU28-2030 will be about 13.1 Mha and in Non-EU-2030 it will accumulate 5.6 Mha.

Figure 1.7 Maps of **Low-quality land category**, distribution of unused land according to three potentials types at NUTS3 level (Unit: 1000 ha.)



In Figure 1.7 show the result of data for low-quality land category at NUTS3 level, translated by ArcGIS in graphics maps. And in Figure 1.8 show maps of data result for high-quality land category at NUTS3 level, translated by ArcGIS in graphics maps (e.g. red colour between 0-5 thousand ha released for high quality land), but, for Turkey and Wester Balkans no data is available for 2020 and 2030. Furthermore, in Annex A.2 shows the estimated land by country and potential amount for the year 2020 & 2030.

Figure 1.8 Maps of **high-quality land category**, distribution of unused land according to three potentials types at NUTS3 level (Unit: 1000 ha.)

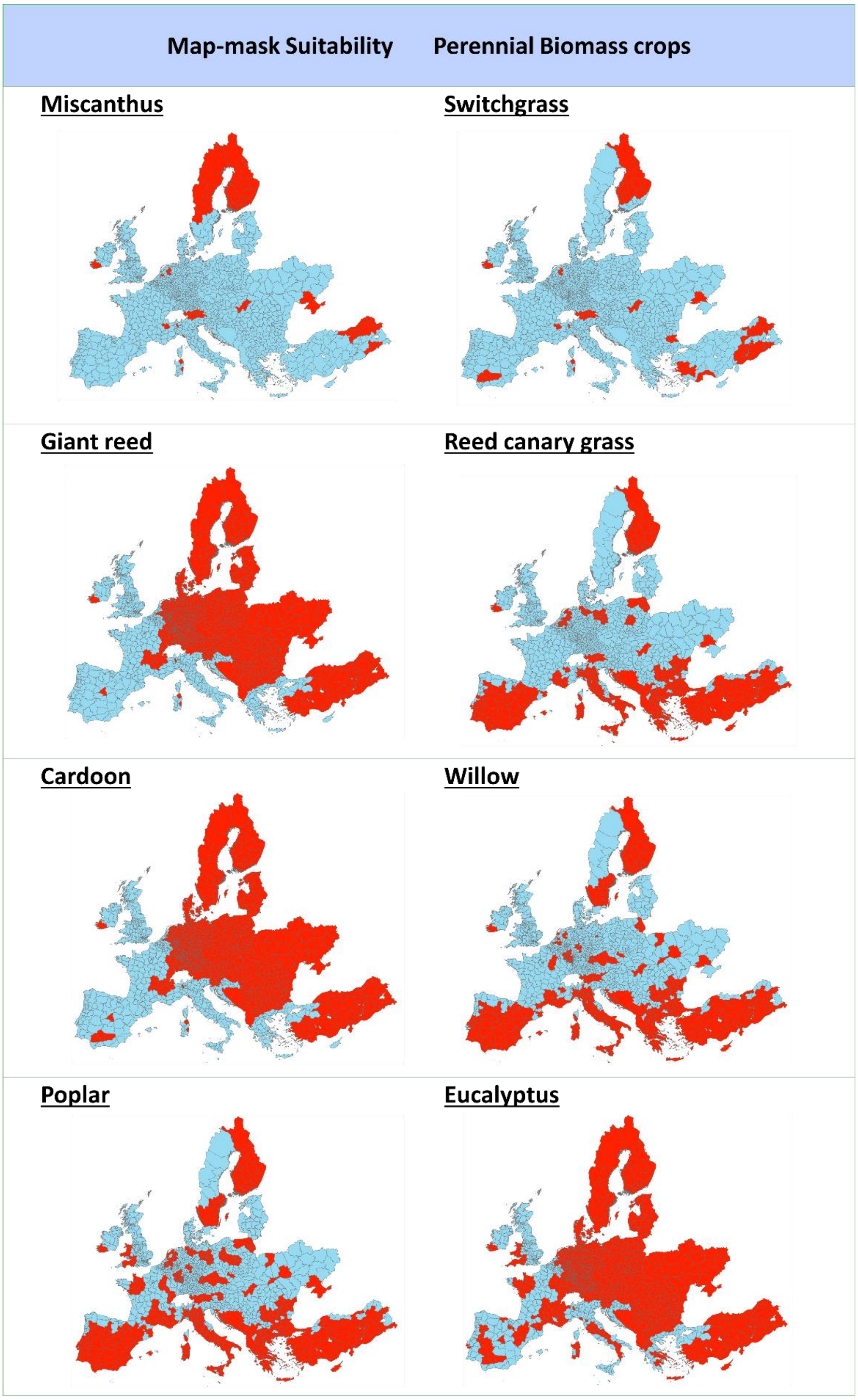


Suitability land

Noticeably, the results of suitability map a NUTS3 level area very variable showing the differences of adaptability according to the biophysical characteristics and features performance in a diverse location in Europe (see Figure 1.9). Therefore, on the maps it is possible to appreciate the suitable/ unsuitable areas, the result of the combination of biophysical variables by each crop. The unsuitable land area is representing in red colour.

The high variability of distribution shows the difference in adaptation between selected crops. On the herbaceous crop group, miscanthus and switchgrass are the crops most adaptable around Europe, this makes their distribution very tentative throughout Europe, that was also reported by Perpiña Castillo et al., (2015). On the other hand, reed canary grass has a smaller radius of dispersion disperse by its characteristics of temperature.

Figure 1.9 Suitability maps for perennials biomass crops. Herbaceous (miscanthus, switchgrass, giant reed, reed canary grass, cardoon) and SRC crops (willow, poplar, eucalyptus).



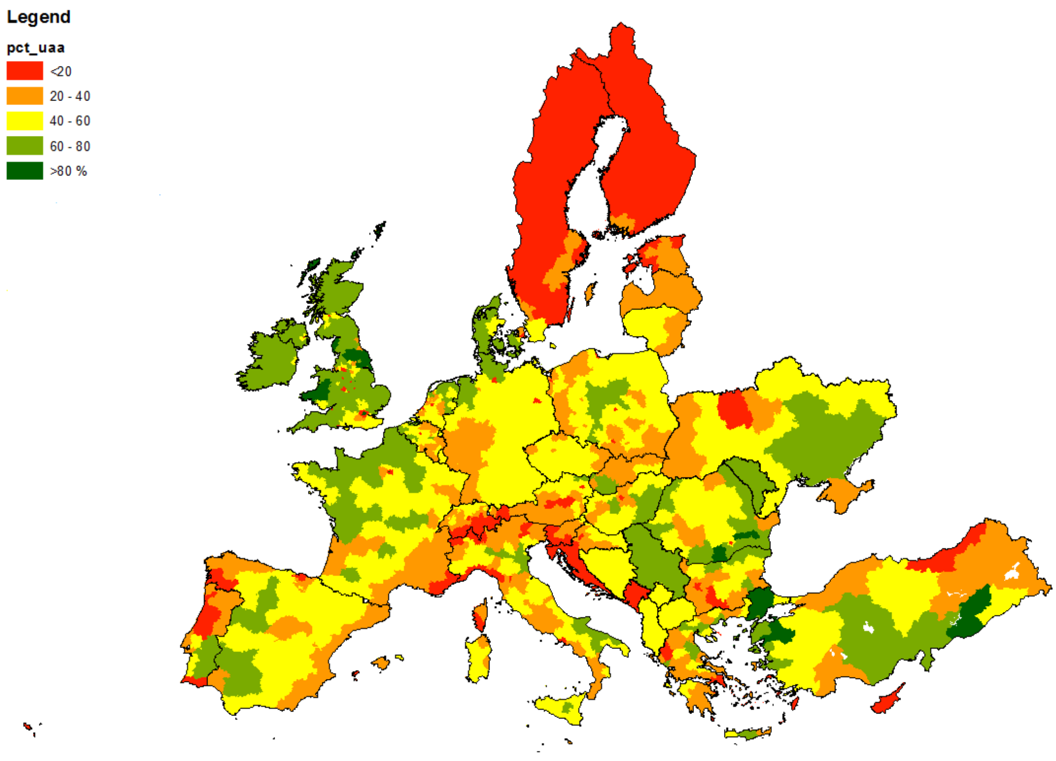
*Unsuitable land area is representing in red color.

DISCUSSION

Land availability

Utilised Agricultural Area, studies of EEA reported over 77 % of the EU territory is classified as rural (47% is farmland and 30% forest) and has 12 million farmers (full-time). Overall, agriculture and the agri-foods industry account for 6% of the EU's GDP, comprise 15 million businesses and provide 46 million jobs. The EU average farm size is 15 hectares (reference data: The US has 2 million farmers and an average farm size of 180 hectares). The result in this study shows UAA average for EU28, covers about 40%, while in the Non-EU countries considered 50% is covered by UAA. Among the countries with the highest percentage of UAA are Ireland (71%), United Kingdom (69%), Serbia (63%) and Denmark (61%). In contrast, the countries with the lowest UAA percentage are Sweden (7%), Finland (7%), Cyprus (13%) and Montenegro (16%). That can be due extreme climate and unfavourable soil & terrain condition for agricultural production. (Table 1.1). Finally, in EU28 the Total Polygon Area is 422.4 Mha, that is covering in average around 40% of UAA (167.7 Mha). Besides Non-EU countries considered have 161.4 Mha total polygon area where the UAA cover in average around 50% (80.9 Mha).

Figure 1.10 The ratio of Utilised Agriculture Area (UAA) respect to the total polygon area at NUTS3 level. Thus, in red color shows area with UAA < 20% and green color shows area with UAA > 60%. *Source*: FSS & Eurostat



Unused land

Identification of suitable and available land types to produce biomass crops is essential as part of the potential assessment. The land referred to must not alter current and future food production (avoid competition with food crop). BEE handbook reported two categories of land have considered to produce biomass energy crops that do not compete with the production of food, as stipulated in the sustainability criteria: surplus land and degraded or low productive land (Vis et al., 2010). In other hand, Dauber et al., (2012), indicates the Surplus Land can be as the all-embracing umbrella term for areas potentially available for bioenergy cultivation and it may cover fallow land, set aside, abandoned land, 'marginal land', degraded land, reclaimed land and waste land. Therefore, in this study made consider as potential areas which can be used for perennial biomass 3 types of unused land: Low-medium, high-quality land and fallow land.

Land availability for Biomass lignocellulosic crops

Estimation reported in Biomass Future Project, taking under consideration important parameters such as *yield increases* and *population changes*, indicates the available land in EU27 for non-food crops will increase to 20.5 Mha in 2020 and to 26.5 Mha in 2030. In other hand, the simulations by Don et al., (2012) predicted that 17-21 Mha of land must be converted to energy crop production to meet the targets of bioenergy share set by EU policies for 2020.

Table 1.8 Studies concerning land potential for energy crops in the EU. Table modified from EEA, 2007.

Authors	Land Potential	Time horizon
Faaij, 1997	40 Mha in EU-15	2010 onwards, food and fibre first
VIEWLS, 2004	35–44 Mha in EU-10	2020; food and fibre first
WBGU, 2004	22 Mha in EU-25	ecological constraints (fallow/released land)
Yamamoto, 2001	30 Mha in Europe	By 2025, food and fibre first
Thrän et al., 2006	59 Mha in EU-25	2020 bottom up
Thrän et al., 2006	29 Mha in EU-25	2020 bottom up + ecological constraints: lower yields and nature conservation
EEA, 2007	20 Mha in EU-25	2030 bottom up + environmental constraints
EU, 2007	17.5 Mha in EU-27	2020, about 15% of arable land would be used.
4Fcrops cited from Alexopoulou et al., 2010	26.5 Mha EU-27	2030 bottom up (NUTS2)

Elbersen B. et al., 2013	18.3 – 21.7 Mha EU-27	2020 for reference and sustainability scenario (NUTS2)
Perpiña Castillo et al. 2015	14.5 Mha in EU-28	2050 bottom up (NUTS3)
This study	13-15 Mha in EU-28	2030 bottom up + environmental constraints (NUTS3)
This study	5-6 Mha in Non-EU*	2030 bottom up + environmental constraints (NUTS3)

Result in the *Base potential* show the reduction land is because was exclude protected area, thus, the prevention of the loss of highly biodiversity areas or areas with high carbon stocks are not used for dedicated cropping was made. Then, to avoid monoculture choosing mix of the least three perennials crops per region was considered. Potential of land availability to perennials biomass production amount in Base potential, for EU28-2020 has about 13.8 Mha and EU28-2030 has about 15.2 Mha. Result in *Strict suitability potential* (UD01), it is concluded that the total of available land (low and high quality land) according to the most stringent potential in EU28-2030 will be about 13.1 Mha and in Non-EU-2030 it will accumulate 5.6 Mha. Limitations of data-source for CLC, HNV are not cover all study area (37 countries) and CAPRI model (Table 1.9).

Table 1.9 Land availability in technical, base and UD01 potential to low and high quality land categories for the year 2020 and 2030 (Unit: Million ha).

	Technical potential	**Base potential**	**UD01 pot.**
		2020	
EU28	18.3	13.8	11.7
Non-EU*	12.8	6.4	5.7
Total	31.1	20.2	17.4
		2030	
EU28	19.9	15.2	13.1
Non-EU*	12.5	6.3	5.6
Total	32.4	21.5	18.8

The results indicate that many countries in the EU28 and Non-EU will experience an increase in the amount of unused land, as Spain and Turkey show, and that according to our results this situation would be maintained until 2030. Therefore, it is necessary to implement actions to reduce and recover unused land and thus prevent degradation and loss of land resources.

Land suitability

The suitable area depends primarily on crop agroclimatic and biophysical request. Detailed weather data from MARS and an extensive literature survey on crop trials were used to assess and incorporate the limiting factors to come to a classification of crop performance in extensive systems on marginal lands and intensive systems on medium quality soils. The result of land suitability show map-mask generated at NUTS3 level resolution, that indicates the suitable/unsuitable according to biophysical variables. Results are very variable where present the differences adaptability between crops and the differences characteristics in the wider EU and neighbouring countries. In some cases, the suitable land for a specific crop is larger than expected, this may be due to the parameters considered, which were limited by the database, but serves as a basis for future estimates and simulations.

It can find information about the allocation at global level on the Global Biodiversity Information Facility (GBIF) and CABI (Centre for Agriculture and Biosciences International). Distribution of biomass crops in Europe, geo-localization spontaneous by human observations for *Miscanthus x giganteus* (www.gbif.org/species/4122678), switchgrass (www.gbif.org/species/2705081), giant reed (www.cabi.org/isc/datasheet/1940), reed canary grass (www.gbif.org/species/5289756), cardoon (www.gbif.org/species/3112364), *Salix viminalis* L (www.gbif.org/species/5372933)., *Salix dasyclados* (Wimm.) (www.gbif.org/species/5583837), *Salix alba (*www.gbif.org/species/5372513).

CONCLUSION

Bioenergy crops will never compete with food and feed crops for high-quality arable soils. In fact, farmers are not willing to turn their land into long-term perennial plantations (15-20 years). On the contrary, they want to be flexible to respond to market changes. In poor soils, however, the economic considerations are different as perennial bioenergy crops maintain relatively high yields and are more competitive than rotational food & feed crops. Low-quality lands are usually those that are released from agriculture first and are potentially usable for bioenergy crops.

In general, it must recognise that although the data come from a well-developed, documented and validated the model as CAPRI, they are still highly uncertain, because they represent a simplification of future reality. Furthermore, models can not include all the factors that influence a situation. Furthermore, in CAPRI the exact location of unused land in each region is not known as the result. On the other hand, the excluded areas regarding the application of RED criteria should be estimated. Consequently, results are likely to be less accurate for regions where unused land resources are distributed unevenly within a region.

Europe should make localised strategies based on the local rustic crops by extending aid towards sustainable farming, thus avoiding erosion, possible desertification and loss of land. The insertion of biomass crops presented in this study, are proposed as an option to reduce the amount of unused land and protect the valuable 'soil' resource. This study also reveals the regions of the EU28 and Non-EU that merit greater interest in agricultural policies. The large amount of released land from agriculture due to various causes, environmental, socio-economic, political and extra conflicts can lead to increase the problem of abandonment, therefore a prior analysis and good management can lead to improving results. The following studies Land availability and Land suitability are expected to have more updated data that will allow a much more detailed (geolocalization) and updated study.

CHAPTER 2

Yield estimation for perennial biomass crop in Europe

Foreword

The provision of biomass by dedicated biomass crops it becomes an important option. It can be expected that the demand for lignocellulosic biomass will continue to grow boosted by the EU targets on the decarbonization of the society. What is then the potential contribution that dedicated crops to the demand of biomass? One factor is for sure the potential their yield in Europe. Although much work has already been done on studying the yielding capacity of perennial biomass crops, a full extrapolation of the yield considering all most promising crops for the whole of Europe was still missing. *This chapter shows indeed the approach used to estimates yield potentials, & yield under water limitation conditions for lignocellulosic crops in Europe*. The AquaCrop model developed by FAO was fed with phenological parameters of the selected species and with spatially detailed weather data in order to simulate the crop growth in all European NUTS3 regions. Furthermore, 3 different agronomic input scenarios (low, medium and high input management systems) were also simulated for each crop with and without water limitation conditions.

INTRODUCTION

Biomass crops have increasingly been studied and consolidated as a source of renewable energy (MIPAAF, 2013) since late 70's (the period of the first petroleum crisis). At present a strategic measure is considered in Europe for the reduction of GHG emissions, and it is likely that lignocellulosic biomass crop production will start to play a growing role into energetic scope. Perennial biomass crops are attractive feedstocks because of their higher biomass yield potential (Kendal et al., 2016) and cellulose/hemicellulose composition to produce advanced biofuels or bio-based products (Alexopoulou et al., 2016). The production of perennials biomass crop depends on several factors include site-specific conditions such as climate, soil conditions, water supply, species, harvesting techniques. From several field trials in a multitude of EU projects (4Fcrops, OPTIMA, Biomass Futures) it has become clear so far that several perennial grasses and SRC crops are suitable to be grown in Europe and that their yielding capacities are promising also in lower productive lands.

However, the expected increased demand for lignocellulosic material from bio-based activities, the large-scale production and yield data of perennial biomass crops is still very limited in Europe. But, is necessary to assess the impact of different input management levels on yields and make strategic decisions for the future (Surendran et al., 2012), insights can come from the use of models able to simulate the potential yield.

Crop growth modelling has been evolved since the late 1960s, supporting the simulation of plant physiological processes and crop growth and development. This evolution has been influenced by the changing goals, target users, and policies over the years, from models with a strictly scientific to those focused on practical applications and impact of management practices ranging from a single crop to complex agricultural systems. This progress imposed different structures regarding the levels of complexity, the selection of algorithms and model crop-growth modules, and input requirements (Todorovic et al., 2009). At the core of any crop growth model, there is a set of equations that estimates the production rate of biomass from the captured resources such as carbon dioxide, solar radiation, and water (Azam-Ali et al., 1994 cited by Todorovic et al., 2009). Thus, three main crop growth modules can be distinguished: (i) *carbon-driven,* modules base crop growth on the carbon assimilation by the leaves through the photosynthetic process, e.g. WOFOST (Supit et al., 1994), (ii) *radiation-driven,* modules derive the biomass directly from the intercepted solar radiation through a single conversion coefficient, called radiation use efficiency (RUE), e.g. CERES (Ritchie et al., 1985), EPIC (Jones et al., 1991), and (iii) *water-driven,* crop growth modules are based on the approach highlighted in that the biomass growth rate is linearly proportioned to transpiration through a WP parameter, e.g. AquaCrop (Steduto et al., 2009), Cropsyst (Stockle et al., 2003).

Furthermore, in the last years, many models for bioenergy crop simulation have been development (Lewandowski et al., 2015) to analysis the potentiality of the herbaceous and SRC crop for biomass. As a consequence, in the course of the years, different types of methodologies to estimate the production of biomass have been studied. For instance, cited by Surendran et al. (2012), miscanthus & reed canary grass (MISCANFOR, Kendal et al., 2016), Switchgrass (DAYCENT, Nocentini et al., 2015), miscanthus (AquaCrop, Stricevic et al., 2015), miscanthus & switchgrass (EPIC, Williams et al. 1984; ALMANAC, Kiniry et al., 1992) and poplar & willow (3PG, Landsberg & Waring 1997).

Much research has already been done estimating crop performance in different regions in Europe, but not all regions are covered (for most promising crop). So, we do not have a European-wide overview of which crops produce more in a given location. That is why it was decided in S2BIOM to develop a yield simulation approach covering the whole European territory taking into account all climatic zones and all potentially suitable perennials for which experience with growing them already exists in Europe. In this study, we used a simple model based on the principal concepts of AquaCrop model developed by FAO (Steduto et al., 2012). Moreover, we considered previous studies as Biomass Futures and ETC/SIA, (2012) which built first approaches to crop growth simulation were done. The atlas produced by Biomass future (atlas of sustainable biomass cost supply at NUTS2) in combination with ETC/SIA, (2012) assess the sustainable potential and production cost for sustainable potential and production cost for perennials biomass crops for EU-27.

This study will give a clearer picture of the yield potential, then provide us with a better understanding of which perennial crops are most suitable to be used for biomass production in every region in Europe. This chapter will describe the methodology, the relevant projects, data sources and tools necessary to determine yield biomass data. Furthermore, it is present a general description of the main characteristics and agronomic requirements for each of the eight crops.

Objectives:

- To collect database from biomass crops (herbaceous and SRC crops) at European level in terms of crop characteristics and yield performance.

- To apply the principal concepts of AquaCrop-model to calculate potential yield for perennial biomass crops (feedstock), based on a series of variable and parameter considered to predict the distribution and potential productivity in diverse climatic conditions in Europe.
- To estimate biomass yield potentials & yield under water limitation (database development).
- To translate the yield simulated under three input system levels, the same as used in the production cost model in Chapter 3.

MATERIAL DATA SOURCES

The study area includes the 28 European countries (EU28) and their Eastern neighbouring countries (Albania, Bosnia & Herzegovina, Montenegro, Republic of Macedonia, Kosovo, Serbia, Turkey, Moldova and Ukraine). In total 37 countries were included in the evaluation at NUTs3 level. The Nomenclature of Territorial Units for Statistics (NUTS), a hierarchical system which divides the European economic territory into economic regions, is categorised in four resolution level as NUTS0, NUTS1, NUTS2, NUTS3 (Eurostat – NUTS 2013 classification), thus, the analysis corresponds to small regions for a specific diagnosis.

Characteristic of the crops

Herbaceous biomass crops, are crops that can be harvested on average once per year over several years without the need for ploughing up and new planting (miscanthus, switchgrass, giant reed, RCG and cardoon). *Short rotation coppice* (SRC), refers to plants and trees that are harvested by cutting the growing stem to its base, allowing the growth of new stems (willow, poplar and eucalyptus).

Table 2.1 General characteristics of perennial energy crops included in the study

ATTRIBUTE	miscanthus	switchgrass	giant reed	RCG	cardoon	willow	poplar	eucalyptus
Latin name	*Miscanthus spp.*	*Panicum virgatum L.*	*Arundo donax L.*	*Phalaris arundinacea L.*	*Cynara cardunculus L.*	*Salix spp.*	*Populus spp.*	*Eucalyptus spp.*
Rotation time/age of plantation (year)	15 to 20	15	15 to 20	10 to 15	10 to 15	12 to 25	12 to 30	12 to 25
Propagation	rhizomes, microprop. plants	seed	rhizomes, microprop. plants	seed	seed	cuttings	cuttings	Cuttings
Harvest period	Annually fall or spring	Annually fall or spring	Annually fall or spring	Autumn / early spring	Late summer	harvested on 3–4 years rotation Winter	harvested on 3–7 years rotation Winter	harvested on every 3-7 years rotation Winter
Dry biomass (Mg ha^{-1} d.m.)	5 to 30	5 to 25	8 to 37	3 to 15	5 to 23	10 to 30	7 to 28	10 to 26
Fertilizer input (N) (kg ha/N/year)	0 - 100	0 - 70	50 - 100	50 - 140	50 - 100	80 - 150	110 - 450	60 - 125

Eight crop species were selected from a list of the most promising lignocellulosic biomass species (Alexopoulou et al., 2010), per geographical coverage extension, literature data availability, physiological and agronomic traits. Table 2.1 report main general characteristics of the selected dedicated crops.

Crop parameters and phenological factors

The main crop parameters and crop data collected for the implementation of the model:

- *Phenology,* is the study of periodic plant life cycle events and how these are influenced by seasonal and interannual variations in climate, as well as habitat factors.
- *Growing Season (GS),* is the part of the year during which local weather conditions as rainfall and temperature permit normal plant growth. While each plant or crop has a specific GS that depends on its genetic adaptation and are divided into four stage/phases: (i) Initial: from crop sprouting to the beginning of stem elongation; (ii) Crop development: stem elongation. (iii) Mid-season: from the end of stem elongation to the beginning of canopy senescence. (iv) Late season: from canopy senescence to the end of water uptake (Triana et al., 2014).
- *Length of Growing Season (LGS),* is the duration in days of a total growing season by year. *Minimum start-day,* is the earliest possible start day of the growing season of a given crop (related with minimum temperature). *Maximum day,* is maximum length defined as a number of days (considering GDD). For perennial biomass, the duration of GS is between 170-330 days.
- *Growing Degree Days (GDD or DD),* is the sum of daily temperatures (in °C) from start to end of the season to predict plant development rates. The base temperature (Tbase) is the temperature below which plant development stops, the most common base for calculations is 10°C. Formula: $\mathbf{GDD = \sum (T_{max} + T_{min})/2 - T_{base}}$
- *Minimum temperature* (°C) is the temperature above which the crop becomes active to start the growing season. Minimum and maximum temperature in growing season for perennial biomass crop were indicated by Alexopoulou et al. (2010).
- *Water requirement minimum,* depend on species & variety, growth phase, climate and the length of growing period. In this study for each crop a data has been collected. In other hand, Crop water requirement was defined by Doorenbos, J. & Pruitt, W.O. (1977) as "the depth of water needed to meet the water loss through evapotranspiration (ET_{crop}) of a disease-free crop, growing in large fields under nonrestrictive soil conditions including soil

water and fertility and achieving full production potential under the given growing environment".

- *Harvest index (HI),* for most crops, only part of the biomass produced is partitioned to the harvested organs to give yield, and the ratio of yield to biomass is known as harvest index. Thus, HI alters the portion of biomass that will be harvestable. It is important to note that in AquaCrop, beyond the partitioning of biomass into yield, there is no other partitioning among the various plant organs. This choice avoids dealing with the complexity and uncertainties associated with the partitioning processes, which remain among the most difficult to model (Steduto et al., 2012).
- *Reduction factor to water limitation (*F_{wl}), is a factor reduction derived from GWSI model (ETC/SIA, 2013) and depend on photosynthetic system crop as C3 and C4.
- *Reference evapotranspiration* (ET_0), is a hypothetical grass reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s m^{-1} and an albedo of 0.23. The FAO Penman-Monteith method is recommended as the sole standard method for the definition. This method requires radiation, air temperature, air humidity and wind speed data (Allen et al., 1998). **ΣET0,** is sum daily evapotranspiration in the growing season (mm).

$ET_o = \frac{0.408\Delta\ (R_n - G)\ +\ \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34\ u_2)}$, where: R_n is the net radiation at the crop surface (MJ m^{-2} per day), *G* is the soil heat flux (MJ m-2 per day), *T* is the average air temperature (°C), [T = (Tmax + Tmin)/2] (°C), Tmax = daily maximum air temperature (°C); Tmin = daily minimum air temperature (°C), u_2 is the wind speed at 2 m height (m s^{-1}), e_s is the saturation vapour pressure (kPa), e_a is the actual vapour pressure (kPa), Δ is the slope of the vapour pressure curve (kPa °C^{-1}), and *y* is the psychrometric constant (kPa °C^{-1}).

- *Crop evapotranspiration* (ET_c) differs distinctly from the reference evapotranspiration (ET_o) as the ground cover, canopy properties and aerodynamic resistance of the crop are different from grass. The effects of characteristics that distinguish field crops from grass are integrated into the crop coefficient (K_c). Formula: $\sum \mathbf{ET_c = \sum ET_0 * K_c}$
- *Crop coefficient (K_c),* is the ratio between Crop Evapotranspiration (ET_c) and Reference Evapotranspiration (ET_0). The K_c calculation for each growth stage is according to crop coefficient method (Allen et al., 1998) the following formula: $\mathbf{K_c = \sum ET_c / \sum ET_0}$
- *Crop Transpiration (Tr),* Crop transpiration when well watered (Tr_x) is proportional to the canopy cover and hence continuously adjusted throughout the simulation for transpiration, given by: $\mathbf{Tr_x = CC'^*Kc_{tr,\ x}{*}\sum ET_0}$ (assumed under unlimited water). In other hands, Crop transpiration considering the water stress, given by: $\mathbf{Tr = Ks{*}Tr_x}$ where CC' is canopy cover

adjusted for micro-advection, $Kc_{tr,x}$ is coefficient for crop transpiration and Ks is stress coefficient (specific for each target process).

- *Water Productivity (WP)*, refers to crop production in relation to total water consumed, WP terms are not dimensionless (Heydari, 2014) but both do not need to have the same units (terms are not dimensionless), for instance, WP is 50 kg grains per 1 m^3 of water. Water productivity is a different term of Water Use efficiency (WUE), but in some scientific articles it is reported as WUE (Ragab, 2014).
- *Water use efficiency (WUE)*, is a dimensionless ratio of the total amount of water used to the total amount of water applied (Heydari, 2014). is the % of water supplied to the plant that is effectively taken up by the plant, for instance, that was not lost to drainage, bare soil evaporation or interception (Ragab, 2014). Generally, efficient water use is defined as the ratio between the actual volume of water used for a specific purpose and the volume extracted or derived from a supply source for that same purpose. For instance: the relation of volume utilised (m^3) per volume extracted from the supply source (m^3). According Triana et al. (2014) is the ratio between above-ground dry yield (AGDY) biomass at harvest and cumulative crop evapotranspiration. Formula: $\mathbf{WUE = AGDY / \sum ET_c}$

Table 2.2 repots values for all parameters used for the crop yield estimation, as a result of the literature review.

Table 2.2 Water requirement (mm), length growing season (LGS - days), the minimum temperature (°C), growing degree days (°C), crop coefficient (Kc) and water productivity (WP) from literature.

Crop	*water requirement* (mm)*	*LGS (days)*	*min. Temp* (°C)*	*GDD* (C°)*	*Kc **	*WP (g/l)*
miscanthus	*>500*	175 - 217	10	1700 - 2000	0.47−1.4	1.9 - 4.7
switchgrass	*450 - 750*	190 - 220	10.3	2060 - 2540	0.5−1.3	2.6 -3.9
giant reed	*380 - 650*	206 - 223	10	1843 - 3000	0.5−1.7	2 - 6
reed canary g.	*400 - 900*	170 - 190	7	1800	1.24−1.46	1.5
cardoon	*300 - 400*	321 - 325	10	2425	0.5 −1.0	3.13
willow	*>620*	180 - 300	5	2200	0.49-2.7	2.9 - 6.3
poplar	*>600*	180 - 300	7.5	2200	0.42-2.5	3.35 - 5.26
eucalyptus	*>500*	330	10	2400	0.50-1.8	1.64 - 4

* In growing season

Meteorological data source

MARS database (Monitoring of agriculture with remote sensing), gridded agro-meteorological data in Europe. The data were collected from MARS-AGRI4CAST resources Portal of European Commission (MARS, 2014). The daily long-term data average, since 1975, used were temperature minimum, average, maximum (°C), rainfall (mm) and reference evapotranspiration - ET_0 (mm), available on grid cells of 25x25 km. (for more information see the geographic maps in Annex A.3, A.4, A.5).

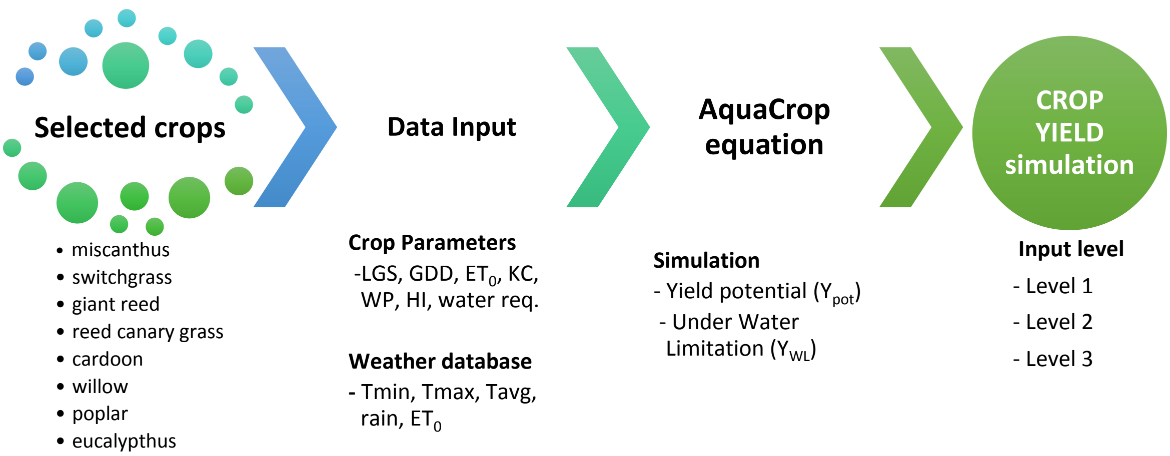
Input Model

GWSI model (Global Water Satisfaction Index), is a crop growth model applied in perennial grasses, takes account the soil and climate characteristics to predicts yield level for C3 and C4 perennial grasses (in a set of regional mean potential and water limited yields), the model is calibrated on real observed yield levels in different region in the Europe (ETC/SIA, 2013).

METHODOLOGY

Yield potential is defined here as the maximum yield (water non-limiting) which could be reached by a crop in given environments, as determined, for example, by simulation models with plausible physiological and agronomic assumptions" (Evans and Fischer, 1999). To assess the yield of the biomass crops the data on daily weather (MARS, 2014) factors, are combined in the AquaCrop model, with the phenological factors determining the crop growth of a specific biomass crop (Table 2.2, for more details see section parameters description above). These factors were derived from a wide range of projects (Table 1) and publications on field trial based assessments with lignocellulosic crops under a wide range of soil and climatic circumstances in Europe. A match is made between the minimal phenological requirements, biophysical characteristics and environmental information for each of these crops to identify the performance and the estimation of yield in each situation. (Figure 2.1).

Figure 2.1. Methodology to calculate the yield biomass of crop response to water.



Simulation and additional calculations steps were:

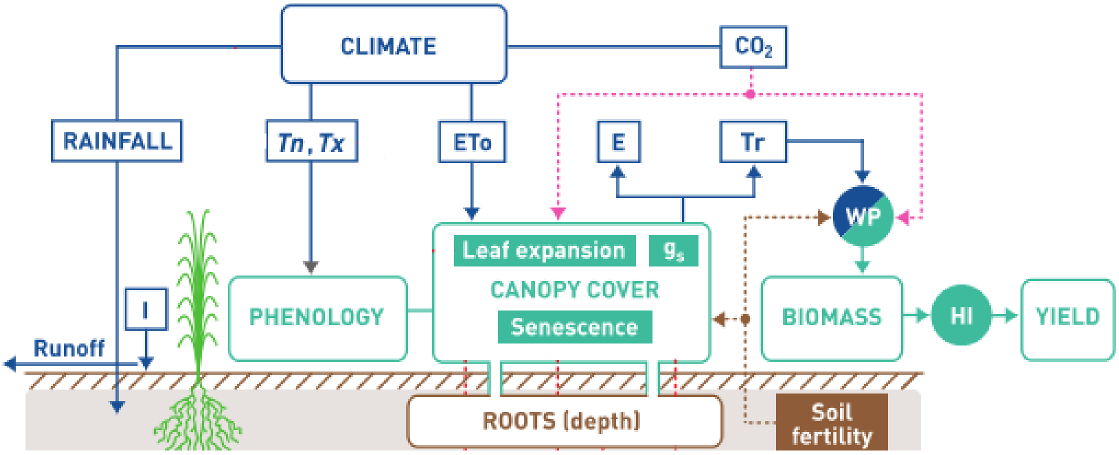
- *Determination of crop growth season per crop for each location*, this is to calculate the duration of growth of the crop by NUTS3, thus, the identification of the first dates and last dates of growth based on the temperature.
- *Determination of crop water use and yield per growing season per crop for each location*, the simulation of yield potential (Y_{pot}) for perennial biomass crop is described considering the equation *1a* and *1b* of AquaCrop model.
- *Estimating a plausible yield level by reducing the potential yield with a percentage in C3 and C4 photosynthetic system*, the relative reduction of the potential was determined as a percentage to be subtracted from the potential yield (Y_{pot}), which is called the reduction factor (F_{wl}) and has been quantified for C3 and C4 type cultures and applied in AquaCrop equations *2a* and *2b*.

Steps are further described in the following text.

YIELD POTENTIAL OF LIGNOCELLULOSIC CROPS IN EUROPE

The biomass yield depends on very site-specific conditions such as soil, temperature and water availability. A direct relation exits between biomass production and water consumed through transpiration. However, existing models apply to bioenergy crops, such as Epic (erosion-productivity impact calculator), Almanac (Agricultural Land management alternatives with numeral assessment criteria), Swat (Soil and water assessment tool) and wrote in different programming languages.
For the selection of the estimation model for perennial biomass in Europe was taken into account, the data of 1480 specific location (corresponding to 1480 NUTS3 codes) and for per eight perennials biomass crops. Crop estimation has been carried out on the base of the principal concepts used in AquaCrop, a simple model (equation) for herbaceous yield estimation. AquaCrop model (figure 2.2), is a crop water productivity model (*water-driven*) produced by the Land and Water Division of FAO - Irrigation and Drainage Paper No. 66 “Yield Response to Water”, developed to implement efficient water management strategies and practices that do not deteriorate the environment and adapt to weather conditions and increase sustainable water productivity and the performance of agricultural systems to mitigate the risks of food security (Steduto et al., 2012).

Figure 2.2 The main components of AquaCrop. Continuous lines indicate direct links between variables and processes (Figure modified from Steduto et al., 2012, not evidence the crop stress component).



Thus, maintaining the original concept of a direct link between crop water use and crop yield, the AquaCrop model evolved from the FAO I&D Paper No. 33 approach by separating non-productive soil evaporation (E) from productive crop transpiration (Tr) and estimating biomass production directly from actual crop transpiration through a water productivity parameter (Steduto et al., 2012). See Figure 2.2, components of AquaCrop, the soil–plant–atmosphere and the parameters driving phenology, canopy cover, transpiration, biomass production and final yield.

The changes lead to the following equation, which is at the core of the AquaCrop growth engine:

AquaCrop Equation: **B = ΣTr x WP** and **Y =HI x B**.

Where: B, biomass produced cumulatively (kg per m^2), Tr, crop transpiration (mm), WP, is the water productivity parameter (kg of biomass per m^2), Y, the attainment of yield and HI, Harvest index. (See Table 2.2).

Thus, above-ground biomass (B) is derived from transpiration by means of the normalised water productivity (WP*, is normalised for ET_0 and air CO_2 concentration), a conservative parameter. At the end of the crop cycle, yield is calculated as the product of the simulated B and the adjusted HI (Steduto et al., 2009). The FAO is calibrating non-location-specific but crop-specific parameters for major agriculture crops, and provides them as default values in the model (e.g. for maize). These parameters are referred to *as conservative*, in that they do not change materially with time, management practices, or geographic location.

In this study, this mechanical model, have been relatively complex considering simultaneously several variables/ parameters related to the physiological processes and climatic condition. For the calculation of simulated processes the core of AquaCrop equation was used and the algorithms wrote in GAMS (General Algebraic Modelling System), the Aquacrop *software* was not used because of the amount of data area covered in the study. Thus, two crop yield potentials (irrigated/non-irrigated) were considered: Yield potential (Y_{pot}) and yield under water limitations (Y_{wl}).

Yield Potential (Y_{pot})

To simulate biomass and yield, the water productivity normalised (WP*) and the representative HI reported in the literature for the chosen crop species under nonstress conditions (HI_o) are required. The WP* is a conservative parameter, and HI_o is conservative to a fair extent but can be cultivar-specific (Steduto et al., 2009). The maximum yield potential in response to unlimited water was calculated with the following equation and was expressed in Mg ha^{-1} d.m.

(1.a) $B_{pot} = \Sigma Tr * WP$ **(1.b)** $\mathbf{Y_{pot} = B_{pot} * HI}$

Yield under Water limitation (Y_{wl})

A *water-limited yield* was simulated assuming that water availability is limited to precipitation and related crop transpiration. A reduction factor ($\mathbf{F_{wl}}$), obtained from the Global Water Satisfaction Index model (GWSI), and depending on the photosynthetic system C3 or C4 was used to account for water limitation in the growing season. The resulting yield was expressed in Mg ha^{-1} d.m.

(2.a) $B_{wl} = \Sigma Tr * F_{wl} * WP$ **(2.b)** $\mathbf{Y_{wl} = B_{wl} * HI}$

Where:
Y_{pot} & Y_{wl}, is Yield potential and under water limitation (Mg ha^{-1} d.m.)
B_{pot} & B_{wl}, is Biomass potential and under water limitation (Mg ha^{-1} d.m)
Tr, crop transpiration (mm)
WP, is the water productivity (kg/mm^3), conservative parameter.
HI, is the Harvest index (%), conservative parameter
F_{wl}, reduction factor to water limitation (%)

To perform the Aquacrop equation some assumptions were made and translated into algorithms.
(i) For water productvity, the atmospheric CO_2 concentration used in WP normalization was not applied, then the data reported in the literature were used as the value of water productivity for each crop. (ii) For the calculation of the water limitation, the coefficient of stress (Ks) is not used, since it is a quite precise coefficient according to the location (this study is at the regional/provincial level), then, to calculate the Potential yield with water limitation, GWSI-model data were used

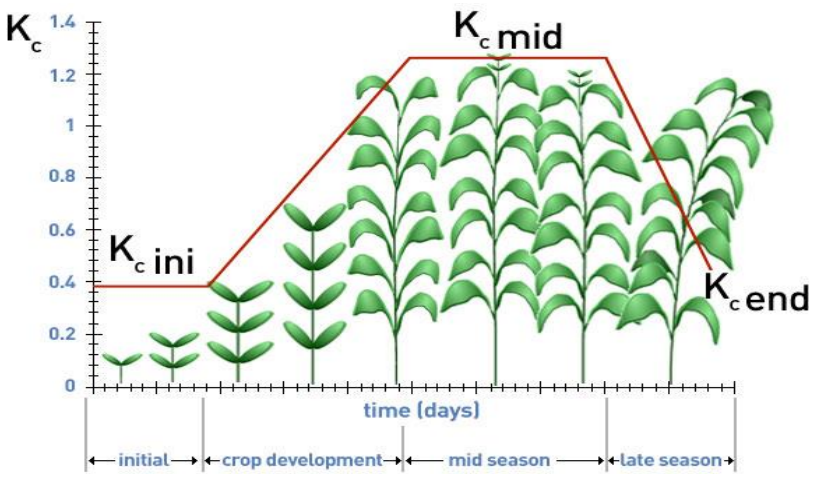
according to the type of photosynthesis (C3 or C4) and the location reports a reduction factor in yield. (iii) So also, the transpiration was calculated assuming that the $Tr = Kc * \Sigma ET0$, where the Kc was divided according to its growth in 4 stadios (initial, develop, midseason, lateseason), according to data found in Literature. Furthermore, the estimation of crop production in future situations was not simulated in this study. On the other hand, the meteorological data that take an important part in the applied Aquacrop equation (such as temperature, rainfall and ET0) were quite accurate, daily data every 25 x 25km since 1975.

Determination of crop growth season for each crop and location

For each location (grid cell or NUTS3 level region) the possibility for a suitable crop calendar is evaluated by identifying the first and latest dates in the year marking the temperature based growing season. The first possible start date is when the mean daily temperature exceeds the required *base temperature* (min_temp_crop), and the final date is when it falls below it. If such days are not found, the start or final day is set at 365. The temperature based start date should be after the *minimum start day*, and the latest of both is selected as start date of the growing season.

Then the length of the growing season is estimated stepwise. First, the temperature sum above base temperature is calculated from the start date until the first day that GDD is exceeded. Divided in four fraction phases as *fraction-initial*, *fraction-development*, *fraction-midseason* & *fraction-late season* (Figure 2.3). That is the day that crop maturity is reached. This day should be before the temperature defined final date, and the earliest of the both is selected as the end of growing season. Then also the length of the growing season is known (Table 2.5).

Figure 2.3 Crop coefficient (Kc) and length of the growing season (LGS)



Start date and length of growing season (LGS) are combined with fractions of Kc phases, and in this way the days of transition to the next Kc phase (initial, development, midseason & late season) can be determined (Table 2.5).

Determination of crop water use and yield per growing season per crop for each location

Once the total evapotranspiration of a crop during the growing season has been calculated, the gross above-ground production (dry biomass) can be calculated with the Water Productivity (WP) expressed in gram dry biomass per Litre water (g/l). The net useful biomass is found by multiplying the total biomass with the harvest index. Assumptions, the WP and HI were assumed conservative data. The crop water use per day during each phase season is calculated as: $\Sigma ETc = \Sigma ET0 * Kc$.
Where ETc is the evapotranspiration of the specific crop. Therefore, each Kc Phase is defined by its duration (in days) since the start of the phase. For each of the four phases, a specific Kc value is applied (see Table 2.5). For each Kc phase, a specific crop coefficient Kc determines the daily crop transpiration demand by multiplying Kc and the daily reference evapotranspiration ET0. Logically, the sum of all daily ETc over the season is the total seasonal crop water use (mm/season) and the potential yield (Y_{pot}) can be calculated as equation (1.b).

This potential yield is the first estimated value of biomass yields for a given crop in a given region. The potential yield can only be realized if throughout the growing season sufficient water is available for transpiration, and that also sufficient plant nutrients are available, and that competing weeds and plant diseases are under control. It depends on field crop management conditions to what degree these conditions are met. In general, the actual yield is clearly much below potential yield, but it can serve as a reference for estimating the room for increasing actual crop yield and for setting targets for a maximum economically attainable yield, which is still below the potential yield.

Estimating a plausible yield level by reducing the potential yield with a percentage WL_C3 or WL_C4

Based on analysis (Elbersen et al., 2012. Biomass Future Project) of the relationship between simulated potential yields of annual field crops and the statistically recorded yield level of these arable crops, using the database of the Unit Monitoring Agricultural Resources (MARS, 2014) of Joint research Centre (JRC) the relative reduction in potential has been determined, as a percentage to be subtracted from the potential yield. This percentage reduction reflects and quantifies the combined effect of all natural and management factors on reducing potential crop yield in a given NUTS3 level. Such a regional crop reduction percentage has been quantified for C3-type crops and for C4-type crops. However, the reduction percent values for both crop types are quite close for a given NUTS-region (NUTS3 district or aggregated tot NUTS0 country level). As on a European scale drought is the most important factor determining major differences between regions and countries in rainfed yield levels, the parameter names for the reduction percentage are WL_C3 en WL_C4. In the case of a C3 crop these values should be applied as following in the table 2.3.

Table 2.3 Attainable yield = Potential yield * (100 - WL_Cx)/100

	WL_C3	**WL_C3**	**WL_C3**	**WL_C4**	**WL_C4**	**WL_C4**
Over all countries	Mean	Min_C3	Max_C3	Mean_C4	Min_C4	Max_C4
average	20.8	9.3	36.9	19.4	8.7	34.8
Max	62.8	47.7	76.4	66.6	49.5	79.6
Min	1.5	0.0	5.6	0.2	0.0	0.6

Table 2.4 National Average WL_C3 reduction % for countries, ranked from southern Europe (Large reduction) to NW Europe (small reduction)

Country	**WL_3**	**Country**	**WL_3**	**Country**	**WL_3**	**Country**	**WL_3**
EL Greece	62.8	BG Bulg	29.4	RO Roman	17.5	BE Belg	7.9
AL Albania	53.2	HU Hung	25.6	SK Slovak	15.6	LU Lux	7.5
PT Portug	53.0	RS Serbia	25.1	EE Eston	13.1	AT Austri	6.3
ES Spain	52.8	FR France	24.3	SI Sloven	13.0	DK Denm	6.1
TR Turkey	52.1	MD Mold	24.2	DE Germ	11.1	FI Finland	5.2
MK Maced	44.9	HR Croat	22.9	UA Ukrain	10.5	LV Latvia	4.9
IT Italy	38.5			CZ Czech	10.4	LT Litua	4.2
				PL Polska	10.0	SE Swed	4.1
						UK UnKi	3.9
						NL Neth	3.5
						IE Ireland	1.5

Table 2.5 Parameters and factors used in crop yield estimation to dedicated cropping

Crop	***minimun water requirement***	***Length season***	***min. start day***	***Accumulative growing season (fraction)***				***min. temp (basetemp)***	***Growing degree days***	***crop coefficient stage (Kc)***				***Photosyntetic system***	***WP***	***HI***
	mm	***day***	***day***	***f. initial***	***f. develop.***	***f. mid season***	***f. late season***	***C°***	***C°***	***f. initial***	***f. develop.***	***f. mid season***	***f. late season***		***g/l***	***%***
miscanthus	500	210	80	0.21	0.34	0.84	1	9	2000	0.48	1.05	1.41	0.95	C4	3.3	0.7
switchgrass	450	210	80	0.18	0.31	0.80	1	9	2220	0.50	0.99	1.30	0.80	C4	3	0.6
giant reed	400	220	90	0.21	0.32	0.78	1	10	2400	0.54	1.01	1.74	1.10	C3	3.1	0.7
rcg	650	190	80	0.20	0.30	0.80	1	7	1800	0.50	1.00	1.40	1.00	C3	2.2	0.6
cardoon	350	250	90	0.10	0.20	0.80	1	10	2425	0.50	0.70	1.00	0.95	C3	3.13	0.6
willow	620	300	80	0.16	0.39	0.84	1	5	2200	0.40	1.00	1.50	0.50	C3	3	0.65
poplar	600	300	80	0.16	0.39	0.84	1	7,5	2200	0.40	1.00	1.50	0.40	C3	2.9	0.6
eucalyptus	500	300	90	0.16	0.39	0.84	1	10	2200	0.40	1.00	1.50	0.40	C3	2.7	0.65

The parameters used to the Yield Modelling are presented in Table 2.5. have been collected from literature-Source: Zegada et al., 2013; Mantineo et al., 2009; Cosentino et al., 2007; Triana F. et al., 2014; Mueller et al. 2005; Katerji et al., 2008; Fernandez J. 2009; Monti et Zegada-Lizarazu 2012; Christou et al., 2003; Hickman et al., 2010; Nassi o di nasso et al., 2011; Garofalo et al., 2013; Curt et al., 1995; Erickson et al., 2012; Sugiura A. 2009; Guidi et al., 2008; Angelini et al., 2009; Stričević et al., 2015; Lasorella, 2014; Curt et al., 1998; Price et al., 2004; Alexopoulou et al., 2015; Bassam, 2010, Kendal et al., 2016.

Yield input system levels

The two yield estimates that have been made, one under full irrigation (Y_{pot}) and one under purely rainfed (Y_{wl}) conditions assume optimum management conditions and should correspond with the highest yields observed in field experiments. In reality, the practical yields are often lower, due to suboptimum conditions such as nutrient shortage or incomplete plant cover.

Table 2.6 The following assumptions were applied on *Yield maximum potential* (Y_{pot}) and *water-limited yield* (Y_{wl}) for a further distinction into three attainable biomass yield levels. Source: ETC/SIA, 2013, p. 245 and Elbersen B. et al., 2012, p. 95.

Input system level	Irrigation	Assumption
High (H)	Irrigation is applied	All crops could reach 90 % of Y_{pot}
Medium (M)	No irrigation is applied, only in the establishment phaseif needed	Attainable biomass yield equals the lowest value of the following two modelled yield levels: (90 % of Y_{pot}) and (100 % of Y_{wl}).
Low (L) (on low-quality soils)	No irrigation is applied	The yield level is limited by water conditions (the lowest value of either 80% of Y_{wl}, or 50% of Y_{pot})

Management of the crop is, therefore, an important factor determining the practical yield levels that can be reached. Simulated maximum yield levels therefore always need correction for management to translate them into practical yields. High inputs through management only make sense if this also results in high yields. High yields can only be reached if water and soil quality is not a limiting factor, or can be compensated enough through management (inputs). If the soil quality is poor, management needs to be tuned to lower inputs, as poor soil conditions, e.g. shallow soils, are challenging to improve, particularly from an economic perspective. Since it is the expectation that it is more sustainable to produce lignocellulosic crops on lower quality soils which have been left unused for food production, it is important to determine yields and cost in both high input systems as in medium and low input systems which enables to match the yield simulation results with all land-soil quality groups. The maximum and water-limited yield simulation results were further converted into three types of yield-input-management levels: high, medium and low input following the rules presented in Table 2.6 according to ETC/SIA, (2013). The 3 yield management level combinations are inputs to the ABC cost model (see Chapter 3) to assessing the Net Present Value (NPV) cost for dedicated crops.

RESULT

Yields translated into three input levels

Figure 2.4 and Figure 2.5 show the yield estimation at NUT3 for SRC and herbaceous, respectively. For herbaceous crops, level 1 is the lowest productive level because of the lower input. According to the maps, level 2 is the best option considering input and output (productivity). In the case of level 3, the high production is visible but this simulation does not consider the cost of irrigation, which would be unsustainable. It can be observed that productivity decreases in the Mediterranean area as the amount of water needed for the crop increases (Figure 2.4 and 2.5, from level 1 compared to level 3). For Northern European countries like Finland and Sweden the low biomass production can be related to the extreme climate.

Figure 2.4 Yield estimation for SRC crops to NUTS3 in three different level of management (input and irrigation). Map-mask suitability has not been considered.

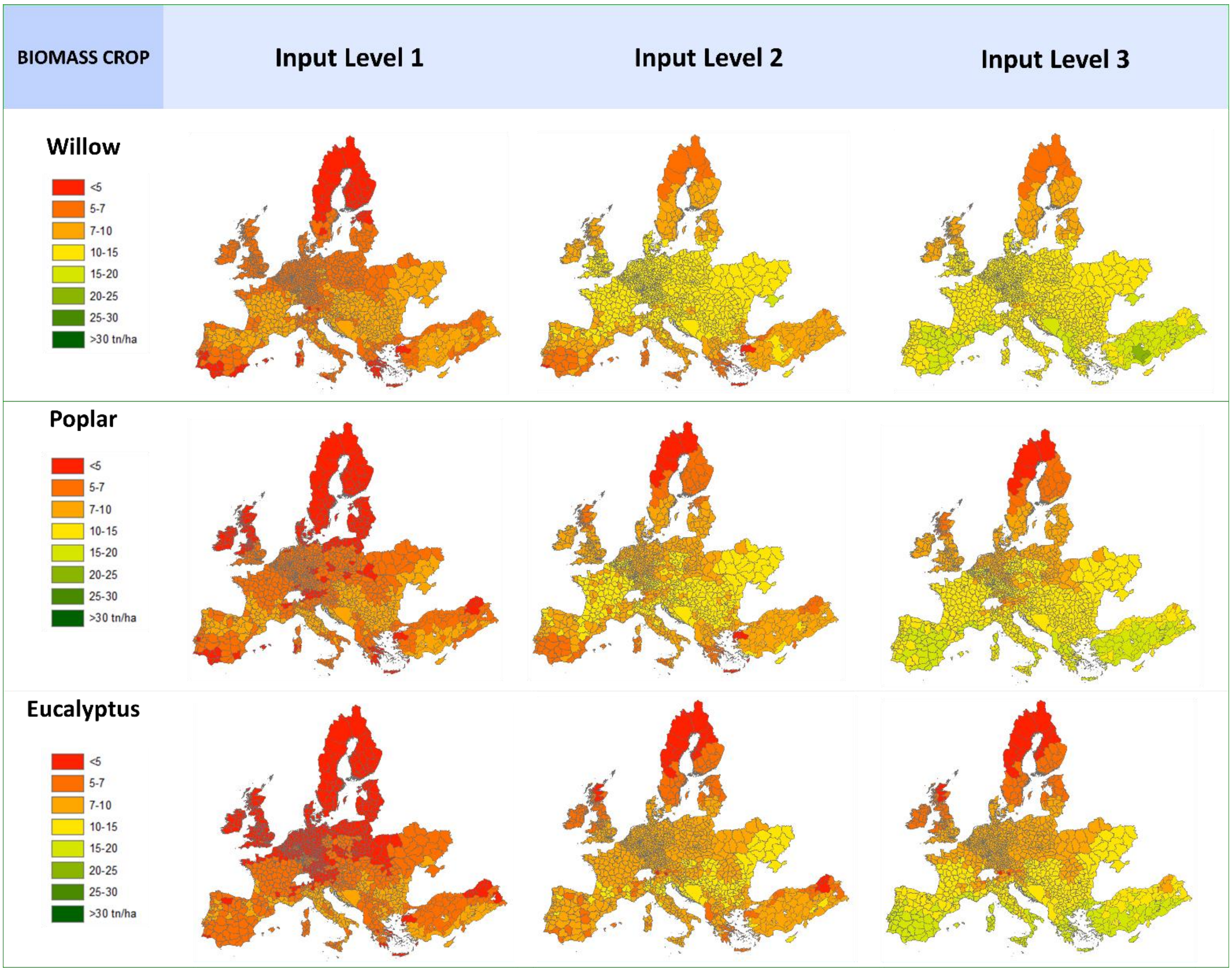
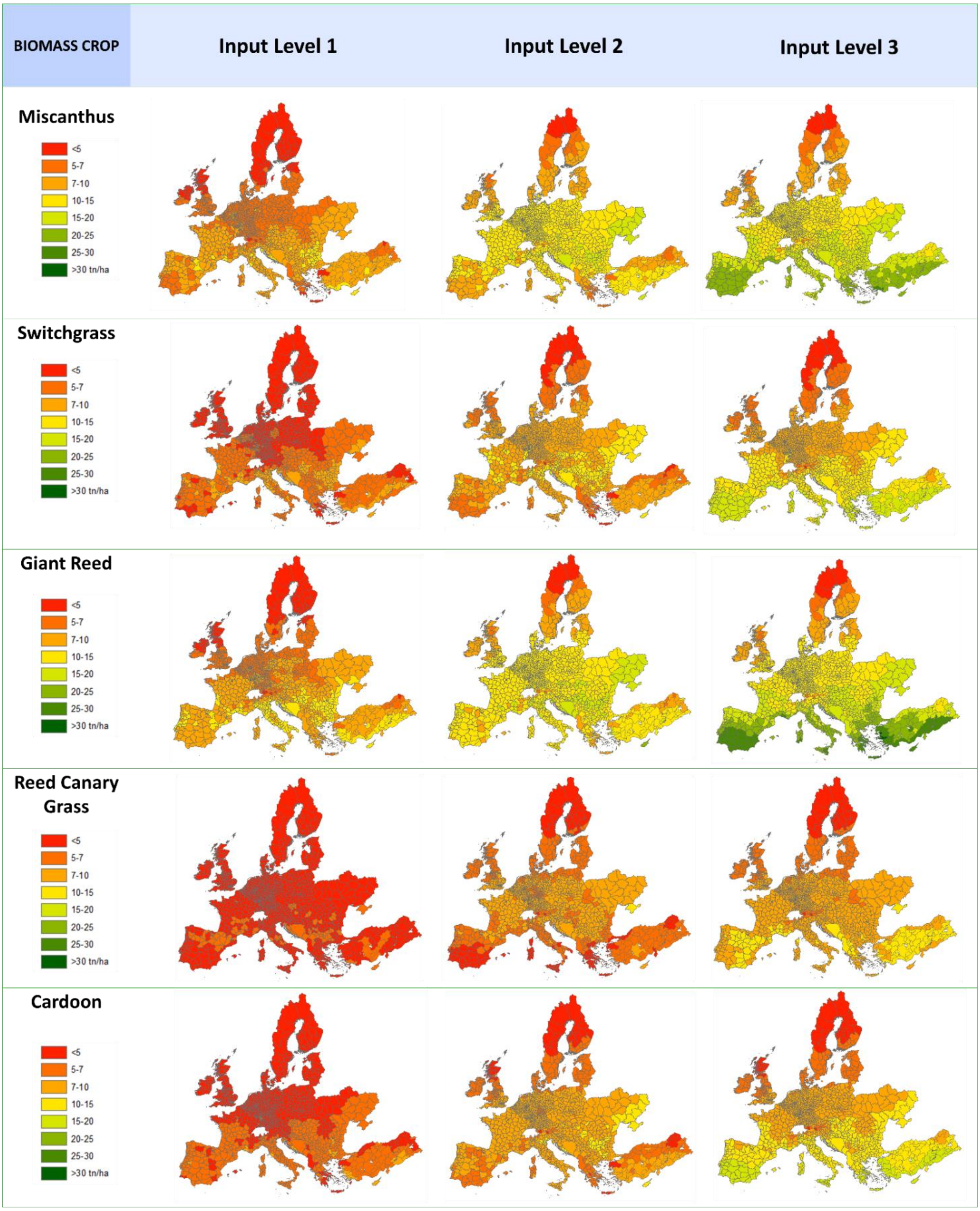


Figure 2.5 Yield estimation for herbaceous crops at NUTS3 with three different levels of management (input and irrigation). Map-mask suitability has not been considered.

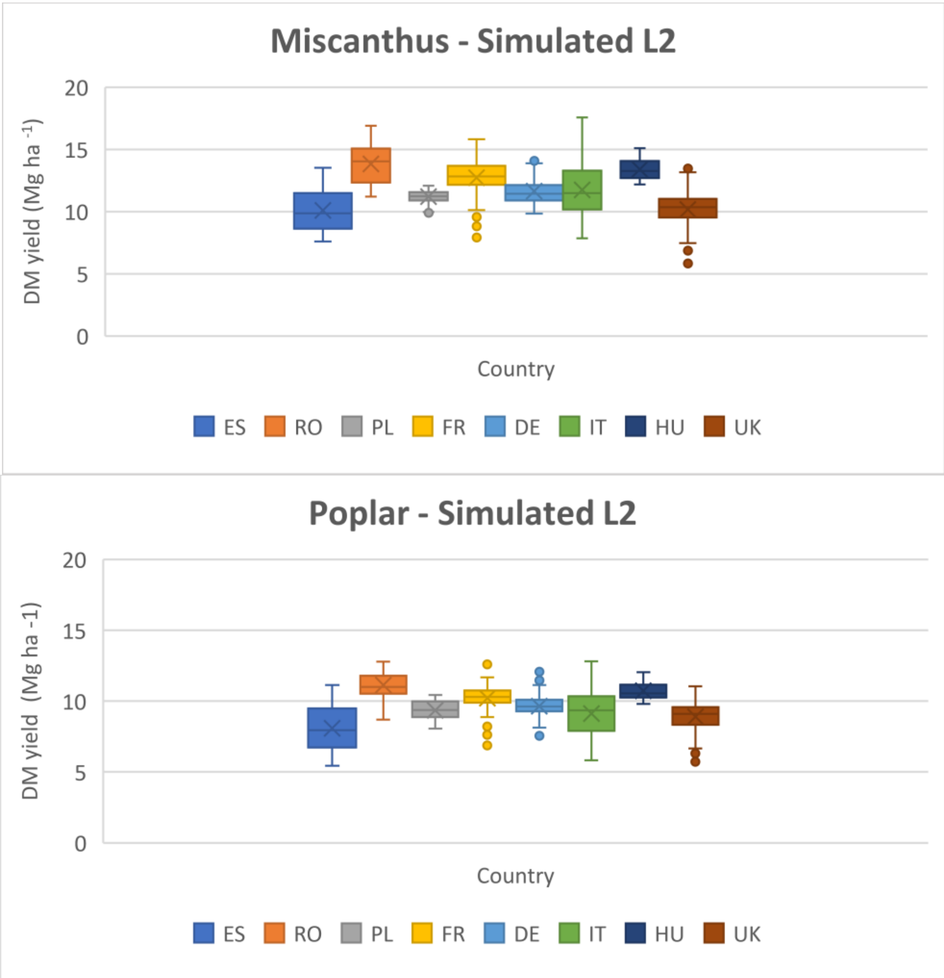


Giant reed and miscanthus are the most productive species at input levels 2 and 3.

As an example, the Figure 2.6 shows the simulated yield potential at input level 2 for miscanthus and poplar in the Countries with the larger area of unused land on the base of the scenario at 2030.

Values for the other crops are reported in Annex A.6. Countries with the higher availability of land, as unused land predicted for the year 2030, are Spain, Romania, Poland, France, Germany, Italy, Hungary and United Kingdom. In the case on miscanthus, Italy shows a big range of variation, ranging from a of yield 8 Mg ha^{-1} to 18 Mg ha^{-1}, as well as for SRC. This can be explained with the high diversification of microclimates. Romania is very promising both for miscanthus and SRC for the implementation of these two crops, as large availability of lands where to grow these two crop with the highest potential yield.

Figure 2.6 Simulated crop yield potential (input level 2) for miscanthus and poplar in the 8 countries with the highest surface of unused land in the 2030 scenario. Crosses indicate the median and boxes include from the 25th to 75th quartiles. The dots out of the range are outliers. For example, in the case of Italy higher variation in data is seen because the climate is very variable in the area (yield 8-18 Mg ha^{-1}). Annex A.6 contains graphs of all the crops.

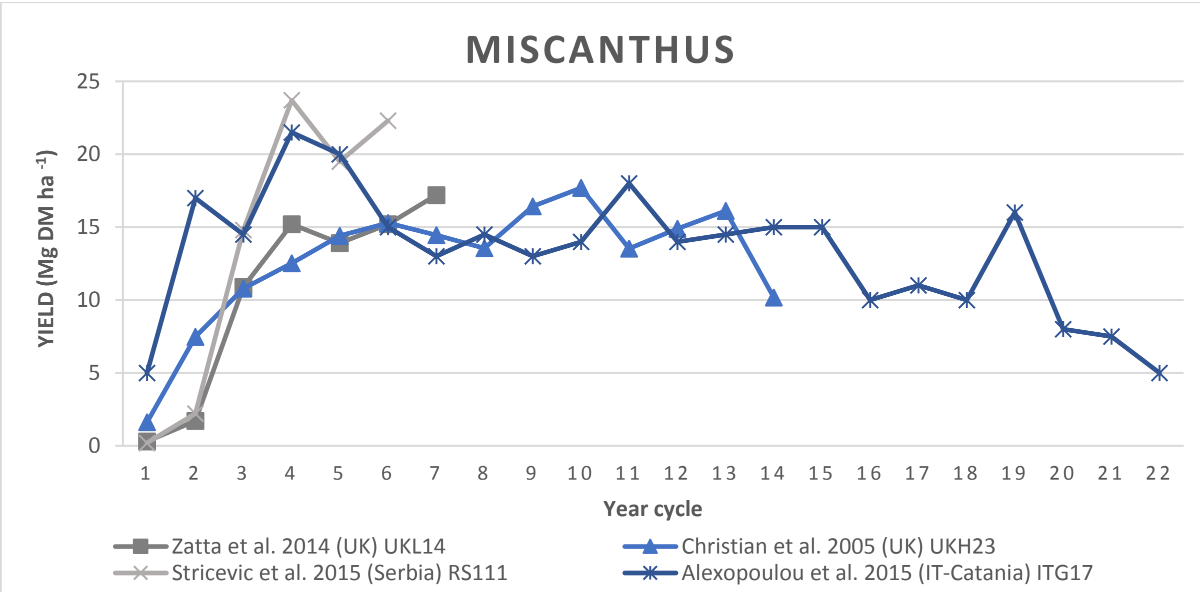


* ES Spain, RO Romania, PL Poland, FR France, DE Germany, IT Italy, HU Hungary, UK United Kingdom.

Observed yield Distribution in Europe

The literature review shows that there are few long-term studies. Studies conducted in UK (Christian et al., 2005), Ireland (Clifton-Brown et al., 2007) and IT-Catania (Alexopoulou et al., 2015) reported data on 14, 15 and 22 year crops respectively (Figure 2.7). Given the higher precipitation and availability of water in northern than in southern Europe, only the studies in the Mediterranean area report irrigation for crop establishment, from the 1st to even the 3rd year in some cases (Alexopoulou et al., 2015; Mantineo et al., 2009). The average biomass yield was 13.4 - 13.6 Mg ha^{-1} for UK and Ireland, whereas the average for Catania was 13.3 Mg ha^{-1} despite the longer crop age (22 years).

Figura 2.7 Yield production (Mg ha^{-1} d.m) of miscanthus in short and long-term trials – Literature data.

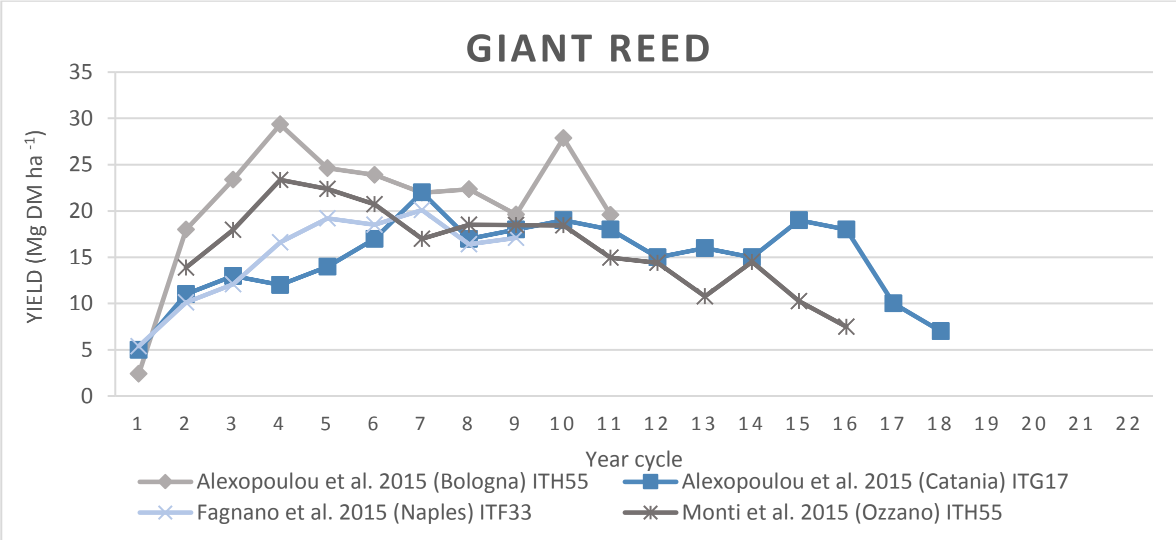


For the other countries, the average yields for miscanthus in long-term trials in Denmark 14.4 Mg ha^{-1} (Larsen et al., 2014), and for miscanthus short-term trials is Germany 12-30 Mg ha^{-1} (Lewandowski, A. Heinz. 2003; Kahle et al., 2001) and Serbia is 16 to 20 Mg ha^{-1} (Stricevic et al., 2015). In France - Grignon, Dufosse et al. (2014) report average yields of 14.2 Mg ha^{-1} in the 22th cycle year. In Northern Italy yields of 19 to 28 Mg ha^{-1} are reported (Lasorella et al., 2011; Angelini et al., 2009), whereas 11 to 30 Mg ha^{-1} are reported for southern Italy (Alexopoulou et al., 2015; Mantineo et al. 2009, Cosentino et al. 2007). In Annex A.9 and Annex A.10, literature data for herbaceous perennials and SRC crops are classified according to location, NUTS classification code, and environmental factors.

Also for the giant reed few studies report data on long-standing crops. Long-term studies (18th years) conducted in Italy in Catania and in Bologna (11th year cycle) report 15.7 and 21.2 Mg ha^{-1}

respectively. Monti et al. (2015) reported 16.8 Mg ha- in Ozzano (16th year cycle) (see Figure 2.8). Whereas Angelini et al. (2009) and Mantineo et al. (2009) report yields higher than 30 Mg ha^{-1}.

Figura 2.8 Yield production in (Mg ha^{-1} d.m. /year) of Giant reed short and long-term trial – Literature data.



Simulated crop yields in relation to observed value: Evaluation

Literature yield data derived from field experiments from European sites (n = 36) were compared with the simulated data (Figure 2.9) to test the robustness of the model simulation. The simulated data fitted the literature data quite well (r = 0.893). The tested crops were miscanthus, switchgrass and giant reed (Table 2.7).

Figure 2.9 Observed versus simulated (modelled) dry matter (Mg ha^{-1} $year^{-1}$) of yields obtained for potential and water limited conditions in European sites.

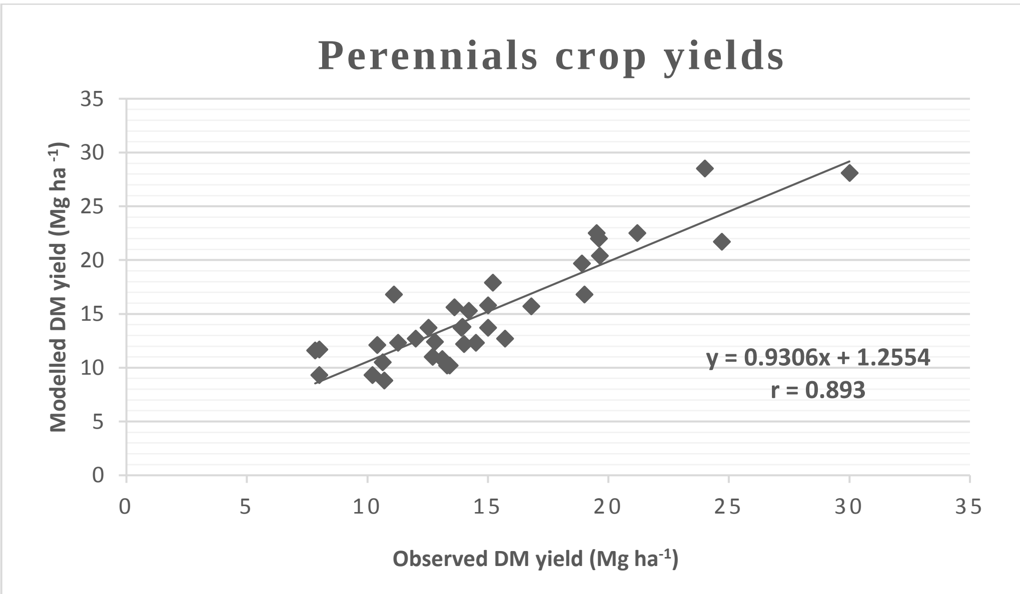


Table 2.7 Comparison of observed (NUTS0) and simulated yields (NUTS3).

Crop	*References*	*NUTS0/ NUST3*	*Observed Yield (Mg ha^{-1} d.m.)*	*Simulation yield potential (YPOT)*	*Simulation Yield under water limit. (YWL)*
miscanthus	Price et al. 2004	UKJ36	14.5	12.3	11.4
miscanthus	Zatta et al. 2014	UKL14	10.63	10.5	10.5
miscanthus	Christian et al. 2008	UKH23	12.8	12.4	12
miscanthus	Clifton-Brown et al. 2007	IE024	13.4	10.2	10.2
miscanthus	Larsen et al. 2014	DK041	13.1	10.8	10.8
miscanthus	Lewandowski and Heinz. 2003	DE124	15	15.8	14.1
miscanthus	Kahle et al. 2001	DE80K	10.4	12.1	11.3
miscanthus	Kahle et al. 2001	DE914	11.27	12.3	11.7
miscanthus	Kahle et al. 2001	DE26C	12.53	13.7	12.3
miscanthus	Stricevic et al. 2015	RS111	18.9	19.7	14.8
miscanthus	Dufosse et al. 2014	FR103	14.2	15.3	13.5
miscanthus	Lasorella et al. 2011	FR223	13.94	13.8	12.7
miscanthus	Alexopoulou et al. 2015	ITG17	13.3	23.6	10.2
miscanthus	Mantineo et al. 2009	ITG16	19.6	22	9.5
miscanthus	Lasorella et al. 2011	ITH55	19.64	20.4	13.8
miscanthus	Lasorella et al. 2011	ITF52	12.7	21.6	11
miscanthus	Danalatos et al. 2007	EL613	24.7	21.7	8.3
miscanthus	M.V. Lasorella et al 2011	NL112	7.83	11.6	11.5
miscanthus	Elbersen et al. 2005	NL113	8	11.7	11.6
miscanthus	Elbersen et al. 2005	NL221	14	12.2	12
giant reed	Alexopoulou et al. 2015	ITH55	21.2	22.5	15.7
giant reed	Alexopoulou et al. 2015	ITG17	15.7	28.5	12.7
giant reed	Fagnano et al. 2015	ITF33	13.9	24.4	13.7
giant reed	Monti and Zegada-Lizarazu 2015	ITH55	16.8	22.5	15.7
giant reed	Monti and Zegada-Lizarazu 2015	ITH55	19.5	22.5	15.7
giant reed	Mantineo et al. 2009	ITG16	30	28.1	12.5
giant reed	Christou et al 2003	ITG17	12	28.5	12.7
giant reed	Christou et al 2003	ITG17	24	28.5	12.7
giant reed	Bacher et al. 2001	DE911	15	13.7	12
switchgrass	Elbersen W. et al. 2005	UKH23	10.2	9.3	9
swicthgrass	Elbersen W. et al. 2005	NL230	10.7	8.8	8.7
swicthgrass	Elbersen W. et al. 2005	DE911	8	9.3	8.8
swicthgrass	Elbersen W. et al. 2005	ITF52	19	16.8	8.6
swicthgrass	Alexopoulou et al. 2015	ITH55	13.6	15.6	10.6
swicthgrass	Alexopoulou et al. 2008	ITF52	11.1	16.8	8.6
swicthgrass	Alexopoulou et al. 2008	EL641	15.2	17.9	5.1

Table 2.8 shows the data at country level (NUTS0) considered as a reference to the evaluation of the simulation result. For more details of the Aquacrop model result for lignocellulosic crops on yield potentials and yield under water limitations see the maps in Annex A.7 and A.8.

Table 2.8 Data set used to evaluate the model robustness

Crop	*References*	*NUTS0/ NUST3*	*Observed Yield (Mg ha^{-1} d.m.)*	*Simulation yield potential (YPOT)*	*Simulation Yield under water limit. (YWL)*
miscanthus	Nsanganwimana F. et al. 2014; Khanna et al. 2008	AT	17 to 30	13.4	12.6
miscanthus	DEFRA, 2007	UK	12 to 16	11.3	11.1
miscanthus	Anderson et al. 2011	DK	10 to 17	11.4	11.2
miscanthus	Anderson et al. 2011	DE	10 to 30	13	12.2
miscanthus	Anderson et al. 2011	PT	26 to 39	21.7	9.8
miscanthus	Anderson et al. 2011	ES	14	21.9	10.1
miscanthus	Anderson et al. 2011	NL	16 to 25	12.3	12
miscanthus	Zegada-Lizarazu et al. 2013	review	10 to 30		
miscanthus	Lewandowski et al. 2003	review	5 to 44		
giant reed	Bacher et al. 2001; Oster and Schweiger 1992	DE	8 to 26	13.9	12.3
giant reed	Elbersen W. et al. 2005	DE	15 to 20	13.9	12.3
giant reed	Elbersen W. et al. 2005	ES	8 to 37	25.4	12
giant reed	Elbersen W. et al. 2005	EL	5 to 17	27.9	10.6
giant reed	Elbersen W. et al. 2005	EL	7 to 31	27.9	10.6
reed canary g.	Sahramaa et al. 2003	FI1C2	10.2	5.6	5
reed canary g.	Kandel et al. 2016	FI1C2	13	5.6	5
reed canary g.	Elbersen W. et al. 2005	UKH23	max 16	8.6	7.4
reed canary g.	Elbersen W. et al. 2005	NL113	2 to 8	7.8	7.6
reed canary g.	Elbersen W. et al. 2005	SE	6 to 11	5.8	5.5
reed canary g.	Elbersen W. et al. 2005	DK	9	7.1	6.6
reed canary g.	Elbersen W. et al. 2005	IE	8	7	6.9
reed canary g.	Elbersen W. et al. 2005	DE	7	8.4	7.5
reed canary g.	Lord R.A., 2015	FI	7.5 to 9	5.1	4.8
reed canary g.	Lord R.A., 2015	LT	6.5 to 7.5	6.7	6.5
cardoon	Fernandez et al. 2006	ES300	14	16.4	6.6
cardoon	Mantineo et al. 2009	ITG16	7 to 23.5	17.6	7.8
cardoon	Mantineo et al. 2009	ITG16	7.9 to 26.4	17.6	7.8
cardoon	Fernandez J. 2009.	ES300	6.5 to 16.3	16.4	6.6
cardoon	Angelini et al. 2009	ITI17	13 to 14	14.1	8.5
cardoon	Fernandez J. 2009.	EL	27.9 to 28.6		
cardoon	Fernandez J. 2009.	IT	17.5 to 19.7		
cardoon	Fernandez J. 2009.	IT	7.5 to 12.9		
cardoon	Fernandez J. 2009.	IT	13.3 to 15.9		
cardoon	Optima data expert		5.6 to 18		
willow	Ceulemans et al. 1996	SE	10 to 12	9.5	9.0
willow	Ceulemans et al. 1996	IE	12 to 15	10.6	10.5
willow	Ceulemans et al. 1996	FI	6.5 to 7.6	8.5	7.9
willow	Cuniff J. et al. 2015	UK	14.1	12	11.4
willow	Cuniff J. et al. 2015	UK	11.5	12	11.4
willow	Cosentino et al. 2008; Facciotto et al 2005	IT	3 to 26	14.4	9.1
willow	Cosentino et al. 2008; Di Candilo et al., 2005	IT	13	14.4	9.1
willow	Sugiura, A. (2009)		15 to 22		
willow	Sugiura, A. (2009)		11.7 to 19.6		
willow	Amichev et al 2011		7.4 to 20.7		
willow	Zegada-Lizarazu et al. 2010	review	10 to 30		
willow	Dallemand et al. 2008		5 to 25		
poplar	FAO, 2012 International Poplar Commission	DE	6 to 10	11.1	9.9
poplar	FAO, 2012 International Poplar Commission	IT	6 to 12	14.6	9.1
poplar	Cosentino et al. 2008; Facciotto et al 2005	IT	3 to 25	14.6	9.1
poplar	Ceulemans et al. 1996		27.5		
poplar	Zegada-Lizarazu et al. 2010	review	7 to 28		
poplar	Fazio and Barbanti 2014		12		
poplar	Sugiura, A. (2009)		11 to 28		
poplar		SE		7.5	7.1
poplar		PL		10.5	9.5
poplar		UK		10	9.4
poplar		FI		6.8	6.3
poplar		UA		12.4	11.1
Eucalyptus	Ceulemans et al. 1996	EL	25.5	18.6	7.1
Eucalyptus	Sugiura, A. (2009)		12 to 27		
Eucalyptus		IT		15.36	9.5
Eucalyptus		PT		17.4	8.6
Eucalyptus		ES		17.2	8.1

DISCUSSION

This study integrates a series of very extensive databases and is the only one that has tried to simulate the production of biomass for eight crops across Europe. For perennial biomass crop, the average yield over the whole location is imperative for analysing the potential for cultivation, making a good analysis of the economic & environmental performance of these crops on different soils, and in diverse management systems. These crops have a production time between 10-15 years, and it should be considered that a low yield in the establishment phase and a decrease of the biomass yield over time (see Figure 2.7 and Figure 2.8) due to several factors, can seriously affect the yield of the crop, thus varying the time of coppice rotation or substitution of the crop (Larsen S. et al., 2014).

Thanks to the simulation of the yields that covered all the EU countries and neighbourhood, it is possible for each NUT3 level to identify the crop with the highest yield, under optimal and limited condition. Potential yield (Y_{pot}) was simulated using the core equation of Acquacrop. The yield under water-limited yield (Y_{wl}), was applied a reduction factor (F_{wl}), obtained from GWSI model, and depending on the photosynthetic system C3 or C4. The analysis presented by ETC/SIA, (2013) shows that the potential yield of C3 grass exceeds the C4 yields in the northern half of Europe and in the mountainous areas. However, under water limited conditions the C4 grass has a relative advantage in those parts of the European plain where drought periods occur regularly in the summer, especially in soil regions with a lot of sandy soils. The result get into the light the potential productivity and under water limitation. But, this study the most productive crop is giant reed (C3), followed by miscanthus (C4) and switchgrass (C4). The yield of the giant reed could be justified with the high vigorosity and biomass production that has the crop in the Mediterranean zone and the parameters factor found in the literature. In other hand, according to the study of Nassi o Di Nasso et al. (2011) in the Mediterranean environment, if water availability is not a limiting factor, a C4 species such as miscanthus would be able to optimise its biomass accumulation with respect to a C3 species such as giant reed.

Yield estimation for perennials biomass crops to in three different level of management, **f**or herbaceous crops, level 1 is the lowest productive level because of the lower input. According to the produced maps level 2, is the best option considering input and output (productivity). It can be observed that productivity decreases in the Mediterranean area as the amount of water requirement for the crop increases (see Annex A.14).

In any case, several observations should be taken into consideration when modelling crop yields. Concerning the model equations, Todorovic et al. (2009) reported AquaCrop required less input information than CropSyst and WOFOST, and performed similarly to them in simulating both biomass and yield at harvesting. According to the study of Elbersen et al. (2005), the practical yield estimates of biomass grasses take into account soil quality but assume non-limiting water conditions. Richter et al. (2016) propose the yield estimation using an empirical model, observed on-farm yields and remote sensing for miscanthus. In European projects (Biomass Future and 4FCROPS), the biomass yield was estimated according to the agro-environmental zone (AEZ). Often the model uses the expected average yield of the crop to assess the model, therefore in future studies, it is recommended to consider the production along the time.

In other hand, the conservative parameters considered were applied, such as harvest index (HI) and WUE according to literature and experts' consultation. But, determining the HI level is still challenging given that little experience is available with harvesting these crops so far and the expectation is that technologies will improve the HI.

Lewandowski et al. (2015) cite that high-quality and representative field data are imperative for reliable, high resolution, and efficient simulations of biomass production. But, until now there are some limitations of data quality and availability.

- The yield of perennial biomass crops are not included in national crop databases or in Eurostat. Thus, some countries do report information on hectares of energy and non-food crops but do not specify the crop type or sometimes the energy crop area refers to the energy maize area combined with perennials. As these crops are not yet grown on a commercial scale, a solid database is far from exhaustive. Most of the results derive from the plot and various experiments whose results are difficult to compare since they followed different experimental protocols. For these reasons it is still hard to find ad hoc dedicated non-food/ non-feed grasses & crops categories in statistics. To consider also is the harvest methodology. It still needs to be optimised and can cause loss of material. The actual amount delivered to the biorefinery can be very different from estimated on the field, because of mechanisation and losses during storing.
- For the assessment of the yield simulation of these crops, needs to be interpreted with precaution, because in the case of perennials, the economic duration on the establishment is still uncertain and the average annual yield very variable. Current production data of these crops is hard to find as these are not available from Eurostat Farm Structural Survey nor national agricultural sample and census data. Even if data on current land used for energy crop can be available in the last census on agriculture carried out in 2010, the distinction

between SRC or herbaceous perennials was not considered, because of the very few existing crops.

CONCLUSION

Using the core equation of AquaCrop model, was possible to estimate the production of the most promising biomass crops for the whole Europe at NUTS3 level and for different yield potential and yield under water limitations. Simulated yields reached a good level of agreement with observed values from field trials in several locations in EU, thus making the result of the model being acceptable. Figure 2.9 report the yield level simulated by the model for each crop.

In general, giant reed, miscanthus, switchgrass and poplar are the crops which show the hight yield potential around EU.

CHAPTER 3

Integrated approach for crop allocation based on land availability and crop requirements

Foreword

This Chapter presents the biomass potentials resulting from the integration of yields and cost levels for different perennial crops in different climatic, soil and management situations. The purpose is to select three crop-management combinations per region, which can provide highest yields with lowest costs in unused land in Europe. To realise the integration the results of land availability and suitability maps specific per crop (Chapter 1) were combined with results for potential yield and water limited yields (Chapter 2), and production cost. The costs were assessed with an Activity Based Costing (ABC) model, developed to assess the road side Net Present Value (NPV) per Mg ha^{-1} of perennial biomass. Thus, the yield, crop suitability, land availability and cost simulation results were then combined to identify the best performing crop-management mix per region and to assess the potential biomass production (kton) in the whole of Europe on unused lands.

INTRODUCTION

In this chapter, the integration of all assessment results is described to come to a final selection of the optimal crop mix per region in Europe and calculate the final biomass potential from dedicated perennial crops on unused lands in Europe. To come to this integrated result the following inputs are taken:

- The results derived from the CAPRI model based POST-MODEL assessments on land availability and on land suitability per crop type. The land availability was assessed for Technical, Base and Strict Suitability Potential (UD01). These three types of land availability are guiding in generating the final biomass availability in these three potential situations (Chapter 1).
- The results of the crop yield simulation for the 3 yield levels as described in Chapter 2.

With these inputs the following analysis steps were done:

i. Generate a database specifying per Nuts 3 region what mix of biomass crops is suitable and which yield level is attainable according to crop yield simulation, bio-physical suitability factors per management systems possible (high, medium and low input systems)
ii. Use this database as input to run the activity based costing model to generate Net Present Value cost (€/ton d.m.) levels per crop type, management system and region combination.
iii. Identify per location the top 3 crop-management combinations generating the lowest average Net Present Value cost (€/ton d.m.).
iv. Match the post-model land availability results for the 3 land potential situations with the attainable yield levels of the top 3 crop-management combinations providing biomass for the lowest cost. Calculate the total biomass production potential per region assuming an even land distribution of the 3 crops over the land available per potential situation.
v. Generate biomass potential maps for dedicated cropping potential total and average weighted cost levels and per type of biomass crop.

The inputs used are further discussed. This is followed by a description of the detailed methodological approach use to implement the 5 analysis steps summarised above.

MAIN INPUTS

Land availability

The land availability was assessed as described in Chapter 1, for Technical, Base and Strict Suitability Potential (UD01). These three types of land availability are guiding in generating the final biomass availability in these three potential situations. As discussed already in Chapter 1, CAPRI baseline run results are only a strating point to ensure the land needed for feed and food production now and in 2020 and 2030 are excluded from the land potential for dedicated crops. The purpose of the post-model analysis of CAPRI results is to identify the agricultural lands that remain unused after satisfying the market demand for food, feed and 1st generation biofuel crops. The demand for lignocellulosic biomass from the wider biobased economy, so for biochemicals, bioheat and bioelectricity, has so far not been fully internalised into CAPRI and therefore the baseline results from CAPRI baseline do not reflect a full use of the land potential. The post-model analysis to investigate the potential extension of unused land and its suitability for lignocellulosic crops was carried out in 37 European countries at the Nuts3 level. The identification of the unused land requires the elaboration of a land use balance approach comparing the land use situation in 2008 from CAPRI against the one in 2010, 2020 and 2030. This post-analyses then results in 3 categories of unused lands available for dedicated cropping in maximum unconstrained potential:

1. Unused land, which is land that was in agricultural use in 2008, but not in 2020 and 2030
2. Land that is left fallow in 2010, 2020 and 2030 according to the CAPRI baseline.
3. Land already dedicated to new energy crops (NECR) according to the amount of advanced biofuels that are expected to be based on dedicated lignocellulosic crops as exogenously assessed with the PRIMES model (see above). These NECR lands are consistent with the demand for food, feed and 1G biofuel crop demands according to CAPRI, but do not cover a wider biomass demand for bioheat, bioelectricity and biochemical which is evolving and is expected to evolve strongly towards 2020 and 2030.

To come to a final land availability per potential type application of criteria constrain the land availability. In the *Technical potential,* the RED criteria are hardly relevant except for the inclusion of lands that have been registered as agricultural since 1990 and lands that are not used for productive activities in order to avoid indirect land use change effects. The user defined potential is the most strictly restricted one. Further details on how the land availability for the Technical, Base and User Defined potentials was assessed is presented in chapter 1 of this study.

Land suitability

Crop-specific suitability maps were generated for each crop based on the variability of biophysical factors such as climate, soil properties and topographical aspects. In Chapter 1 it was extensively described how the suitability of land for the whole of Europe per crop type was determined and mapped. The combination of land availability and land suitability results in a database providing information of the land availability per Nuts 3 regions and for the land available a mix of perennial crops that can potentially be grown on these lands. It does not provide information on which the best performing crop is for these lands as this depends on the yield performance which was the next analysis step that needed to be done and that is presented in Chapter 2 of this report.

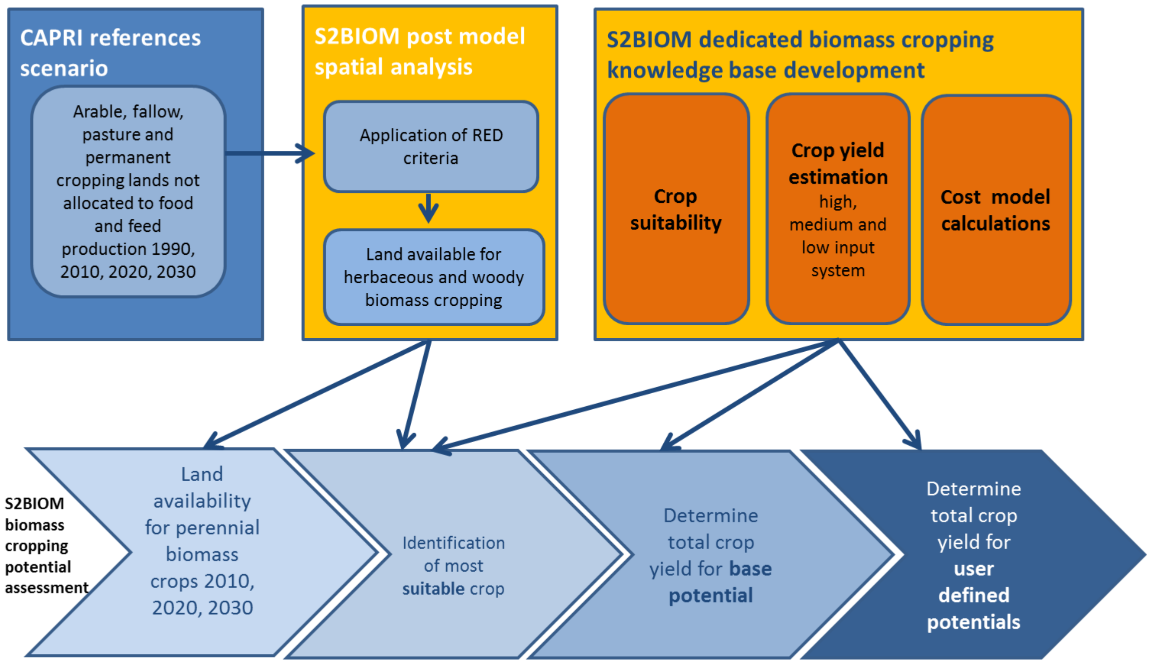
Crop Yield Estimation

A crop yield simulation was done for all 8 perennial crops (5 herbaceous and 3 SRC crops) as is described in Chapter 2 of this report. The AquaCrop model developed by FAO was used for it and fed with phenological parameters per crop and detailed weather data to simulate the crop growth in all European Nuts 3 regions. Yield levels were simulated for a maximum and a water-limited yield situation and further converted to match with low, medium and high input management systems. The results were included in a database containing these 3 yield management levels for all 8 perennial crops at NUTS3 resolution and levels are expressed in tonnes (dry matter). In addition to the yield levels irrigation water requirements per yield-management combination are also specified.

METHODOLOGY

An integrated approach was implemented combining the results of land potential and crop-specific suitability (Chapter 1) and the crop yield results (Chapter 2) and crop yield specific production cost. The integration of crop suitability data with crop yield and cost levels generates a database showing per NUTS 3 regions the hierarchy of crop-management combinations which can provide highest yields with lowest costs and vice versa in unused land in Europe at nuts 3 level (See Figure 3.1). Combining the yield and cost levels of the top 3 of best performing crop-management combinations with the land potentials then results in a final dedicated cropping potential for biomass in a technical potential; a base potential considering currently applied sustainability practices; and a user defined potential for 2012, 2020 and 2030. This potential can be expressed in total biomass production (ktonne dry mass) and in average weighted cost (€/kton dry mass).

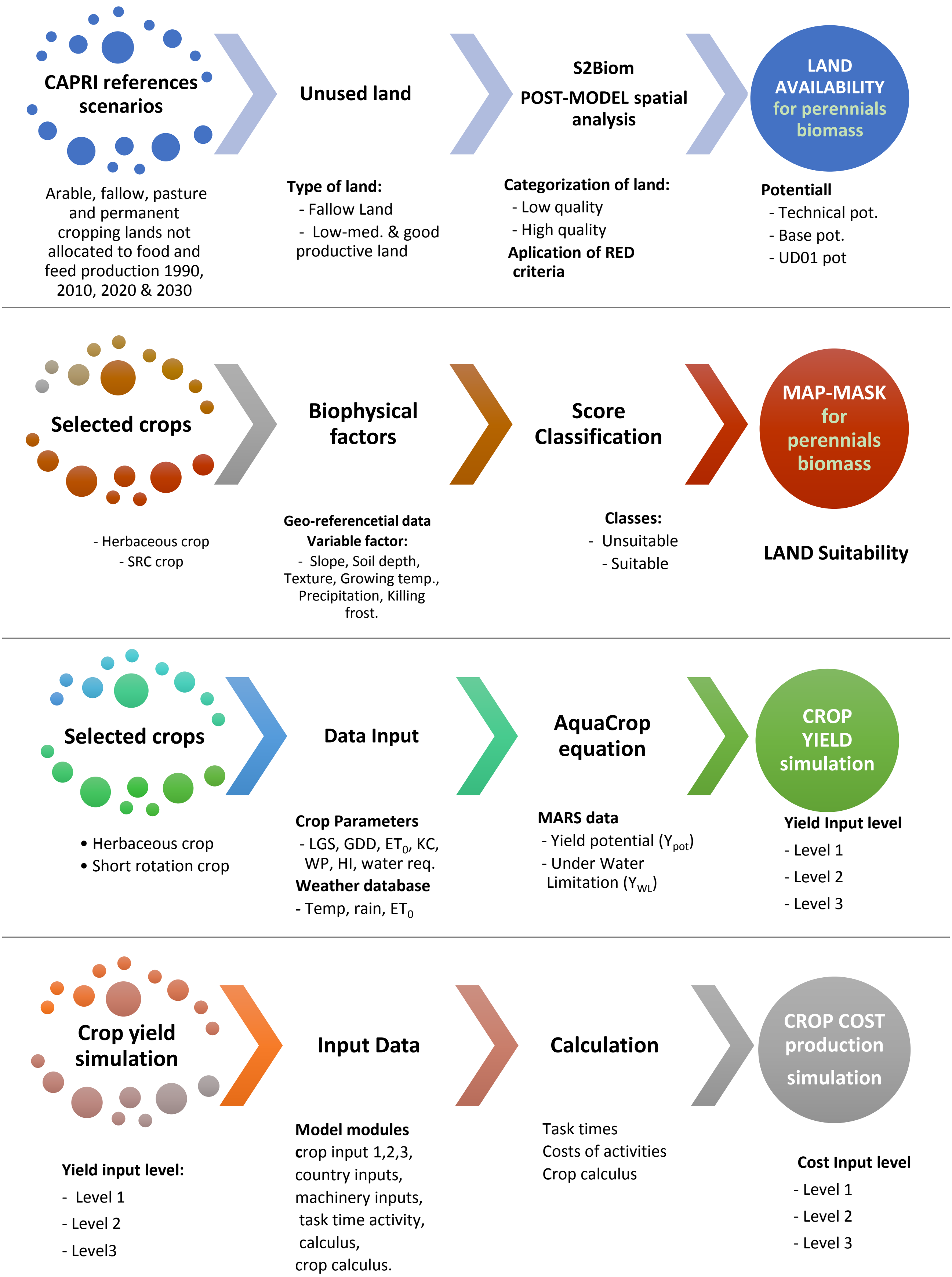
Figure 3.1 Integration of CAPRI land availability for dedicated biomass crops with S2BIOM yield and production cost level assessments to estimate herbaceous and SRC biomass cropping potentials. Source: S2Biom Project (Dees et al., 2017a)



A more detailed overview of the analyses steps followed to calculate the final biomass cost-supply potentials for dedicated biomass crops in Europe will follow here and the description is supported by the schematic overview in Figure 3.2. The following steps were followed:

- Determine for the unused land potentials: (i) what mix of biomass crops is suitable and (ii) identify the location which yield level is attainable per suitable crop- management combination (high, medium and low input systems)
- Calculate for all crop-management combination suitable per region the Net Present Value cost (€/ton d.m.).
- Identify from the cost calculation results per region the top three crop-management combinations generating the lowest Net Present Value cost (€/ton d.m.).
- Match the CAPRI and RED constrained locations with the attainable yield levels of the top three crops and calculate the total biomass production potential per nuts three regions assuming an even land distribution over the different suitable crops and the average weighted NPV cost for dedicated biomass.
- Generate biomass potential maps and a final database for dedicated cropping potential total and per type of biomass crop.

Figure 3.2 Overview calculation in this study of land availability, land suitability, crop yield and production cost for lignocellulosic biomass crop a NUTS3 level.



Calculation of the Net Present Value cost for lignocellulosic crops

1. Development of the activity based cost model

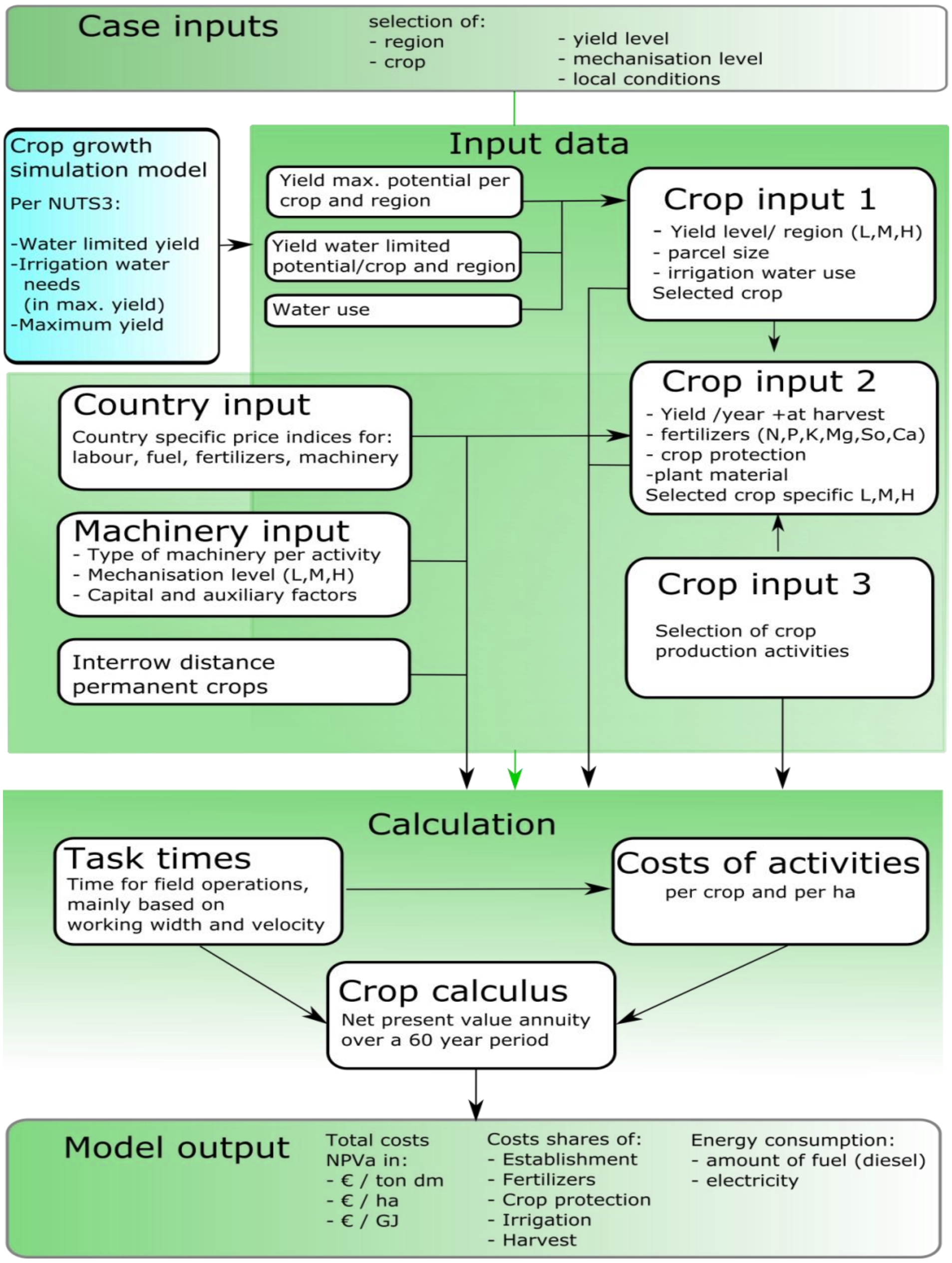
For the calculation of cost of dedicated cropping biomass an excel-based Activity Based Costing (ABC) model (Schrijver et al., 2016; Dees et al., 2017a), was developed to analyse the road side cost per ton dry mass (€/ton d.m.). The cost is only covered in this model up to the farm gate. The model was developed in Excel based Macros and consist of different input and calculation sheets. The ABC model covers the whole production process of alternative production routes that can be divided into logical organisational units, i.e. activities. The general purpose of this model is to provide minimum cost prices for the primary production of biomass feedstock at the road side. ABC generates the costs of different components based on specific input and output associated with the choice of the means of production, varying with the local conditions and cost of inputs (e.g. labour, energy, fertilisers, lubricants etc.). Since the production of most biomass is spread over several years, often long-term cycles in which cost are incurred continuously while harvest only takes place once in so many years, the Net Present Values (NPV) of the future costs are calculated.

In order to assess the cost of a dedicated crop per location in Europe, 8 interrelated excel worksheets in the ABC model need to be filled. This enables calculation of dedicated biomass Net Present (NPV) cost per type of crop, in a 60-year cycle for every Nuts3 region in Europe for low, medium and high input management systems. The plantation lifetime per crop type assumed is as follows: 12 years for SRC willow, poplar and eucalyptus and cardoon and 15 years for perennial grasses. An overview is given of the 8 model modules involved in the calculation of the dedicated crop is given in Figure 3.3 and consists of: Crop input 1, Crop inputs 2, Crop inputs 3, 'Country inputs', 'Machinery inputs', 'Task Time Activity', Calculus and 'Crop calculus' module. (more detail of sequences calculation in ABC cost model for dedicated biomass crops, see Figure 3.3).

The general purpose of this model is to provide minimum cost prices for the primary production of biomass feedstock at the road side. Road side cost is presented as NPV per annum and expressed in € per ton dm. In perennials crops cost simulation, all cost can be allocated to the final product which is the biomass (including land, machinery, seeds, input costs and on field harvesting costs).

Figure 3.3 Overview of ABC cost calculation model for dedicated biomass crops.

Source: Schrijver et al., 2016 and Dees et al., 2017a



2. Apply the ABC cost model to calculate NPV cost for all crop-management combinations per NUTS3 regions for whole of Europe

As main input into the cost calculation the output of yield crop simulation from chapter 2 was used. It covered three types of yield levels for three-input-management levels: high, medium and low input according to the rules presented in Table 2.6 (ETC/SIA, 2013). The 3 yield management level combinations are input into the ABC cost model to assess the Net Present Value (NPV) cost for dedicated crops (Figure 3.3).

Cost-yield combinations per crop and management system

The final results of the assessments provide an overview of cost-yield combinations for the three management levels assumed. They have been generated at the NUTS3 level as becomes clear from Figure 3.4 and Figure 3.5. At the national level, the results are presented in Annex 2. Note that the results in the Tables do not take account of the soil and climatic limiting factors. An important difference occurs between the cost of medium and high yields. This is mostly caused by the high irrigation cost that are needed to close the yield gap between a water-limited yield and a maximum yield. This high cost difference is only seen in the southern European regions where precipitation is limited and irrigation can make a big difference in final yield. From an economic perspective one can however conclude that applying irrigation is not rational as the additional yield does not compensate for the extra cost required. A small yield increase brought about by irrigation can already increase the cost by a factor 10.

Cost of irrigation are high because it requires high investment cost in irrigation installations, fuel inputs for the pumping of water and it needs to be done several times a year, while most of the other activities have a much lower frequency. The price of water itself was set at (0.01 €/l) for all countries, which can be regarded as conservative as in several drought prone countries prices of water can also be expected to increase and it may become common practice to charge farmers for irrigation water consumption, which until now is not common practice.

In the cost model irrigation cost were calculated applying 4 different technologies of which 3 were hose reel system with small to very large pumping capacities and a solar drip irrigation (20 ha, 75 kW el. Pump). The first hose reel systems are much cheaper leading to low machinery investment cost, but require a lot of energy for the pumping of all irrigation water. The solar drip irrigation installation has very high investment cost, but does not need any fuel input. So the energy cost are zero, but the machinery cost are extremely high. The cost of irrigation become particularly high because irrigation application needs to be done several times a year, while most other activities take place in a perennial plantation once a year or less (e.g. sowing/planting, weeding, fertilisation, harvesting). All options for calculating irrigation input result in very high cost levels. They confirm that irrigation in dedicated perennial cropping is just not an option, not even where it can lead to the doubling of the yields as the cost will increase by 20 times at least.

Figure 3.4 Miscanthus yield and cost levels for 3 different management systems (masks for regions unsuitable for these crops given soil and climatic limiting factors)

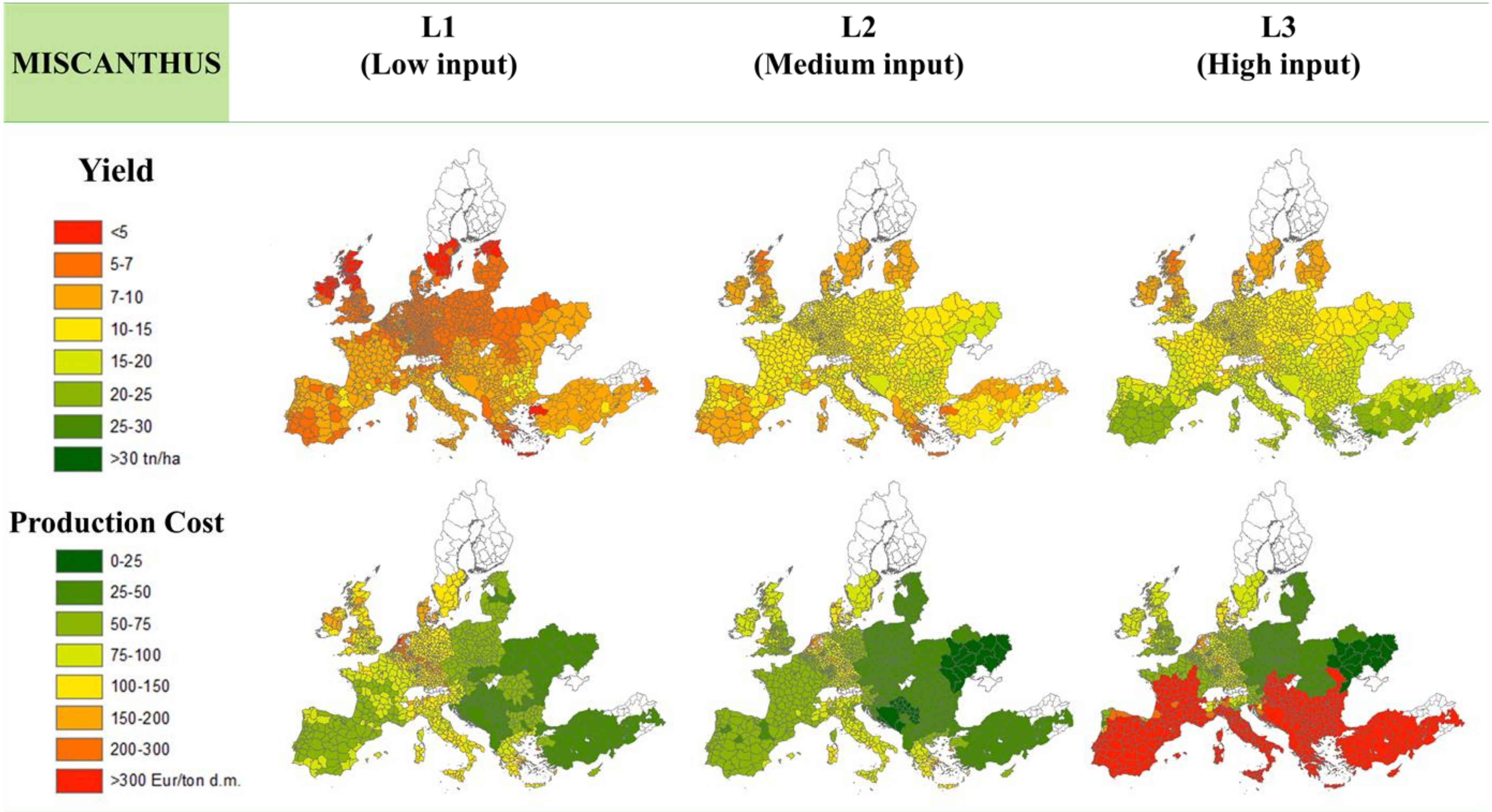
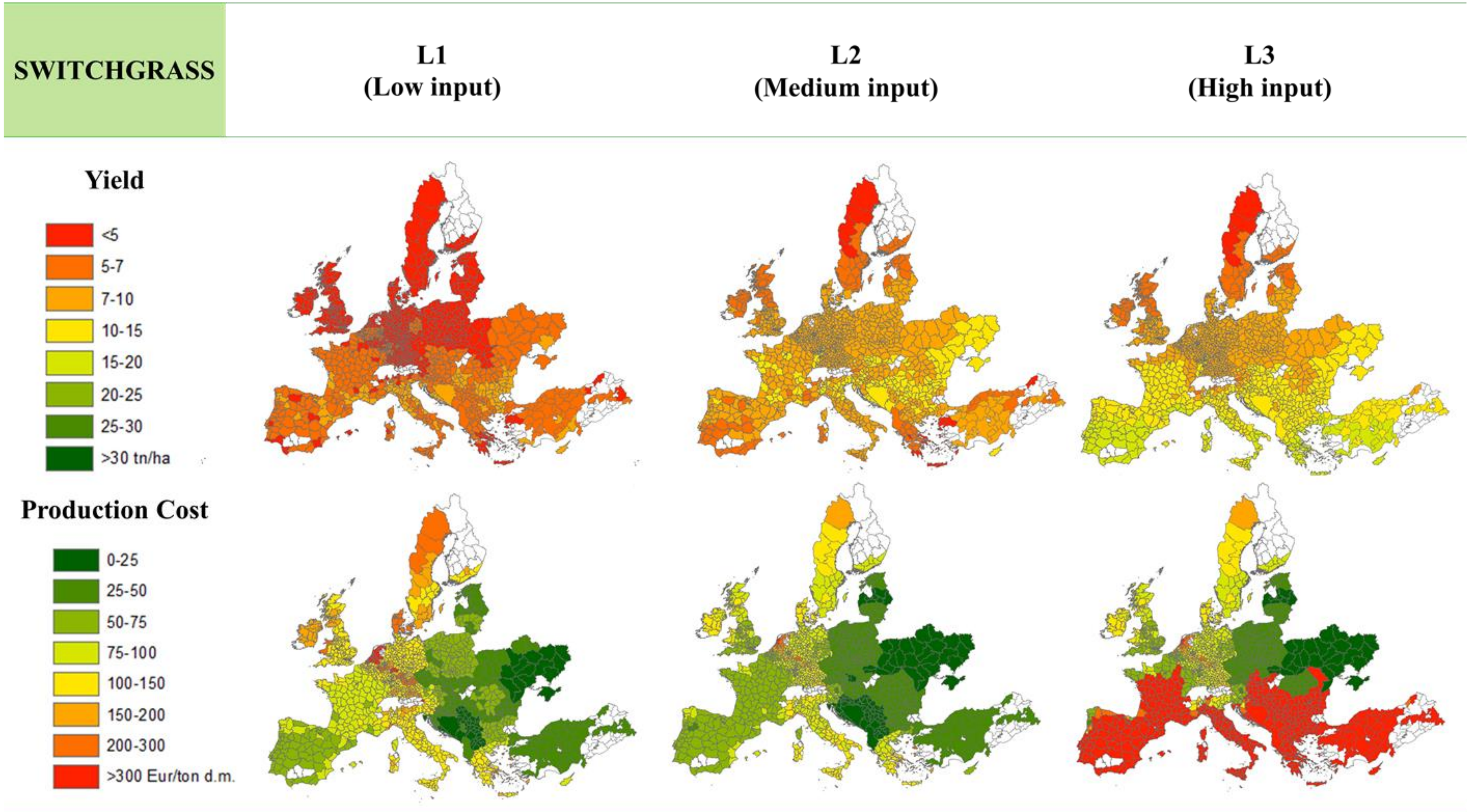


Figure 3.5 Switchgrass (*Panicum virgatum*) yield and cost level for 3 different management systems (masks for regions unsuitable for these crops given soil and climatic limiting factors)



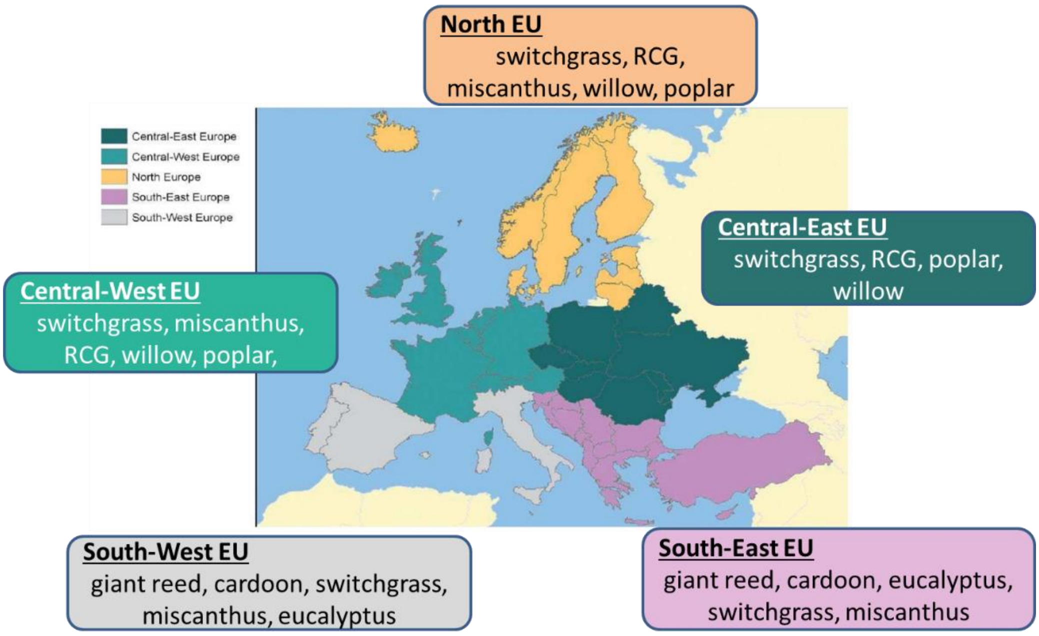
3. Identify the crop management mix with the lowest production cost

The crop suitability, land availability and production cost simulation (including yield crops) results were then combined to identify the best performing crop-management mix per region and to assess the potential biomass production (kton) in Europe on unused lands.

Perennial Biomass crop allocation

Generical presentation in the maps, Figure 3.6 shows the sustainable allocation approach for all crops shared in North EU, Central-East EU, Central-west EU, South-west EU and South-East EU. According to the result, it is possible to identify the distribution of the crops, e.g. in the Mediterranean area the cardoon and the giant reed, in the part of north requiring a climate a little cooler, reed canary grass, switchgrass and miscanthus and willow & poplar.

Figure 3.6 Allocation for the all lignocellulosic crops in Europe.



Best resulting crop mix per region

Mix-Rank allocation approach: selection of three crops at NUTS3 level. In Figure 3.6 and Figure 3.7 show the maps with crop mix-rank allocation (three selection) according the yield, cost, suitability and land availability (*low-quality* and *high-quality*) at each administrative level (NUTS3).

By combining the yield levels, the cost level and the suitability masks per crop type, it could be determined per region what the best crop-management mix would be.

In Figure 3.7 the ranking of the top 3 crop-management combinations generating the lowest average Net Present Value cost (€/ton d.m.) is presented in the case of low input management systems (L1) which links to lower quality lands often characterised as ‘marginal’. Therefore, for the low input systems, the best crop choice for the South-West and South-East of Europe the crops selected are mostly for perennials grasses, particularly for switchgrass, miscanthus, giant reed and cardoon, and for Central-West and Central-East of Europe RCG, willow, switchgrass and miscanthus. For North Europe, the crop selected are between switchgrass, RCG and miscanthus. For instance, in Italy-Bologna (ITH55-code) the crops selected are switchgrass, miscanthus and giant reed. As to the SRC types, these are selected at much lower frequency in the top 3 of low input (L1) crops in this study, because of the higher production cost.

In the medium and high management systems (L2-L3), the ranking of crops in South-West, Central-West and Central-East EU have similar selection of L1 but with input management level L2, while for South-East EU were selected the crops L2 (switchgrass, miscanthus, cardoon, giant reed) and L3 (miscanthus), for North EU were selected L2 (switchgrass, RCG, miscanthus) and L3 (switchgrass), more detail in Figure 3.8. For instance, in the UK and Ireland there are a lot of willow-L2 selected as the first crop, and in the second and third choice, there are an overall increase in switchgrass-L2 and RCG-L2.

Thus, in most cases the choices are all in the medium management class (L2), but sometimes in the regions of the western Balkans and Turkey there is also some high input (L3) miscanthus systems chosen as the second or third option.

Figure 3.7 Top 3 of cheapest crop mixes for low input systems

Rank mix Low Input	Crop 1	Crop 2	Crop 3

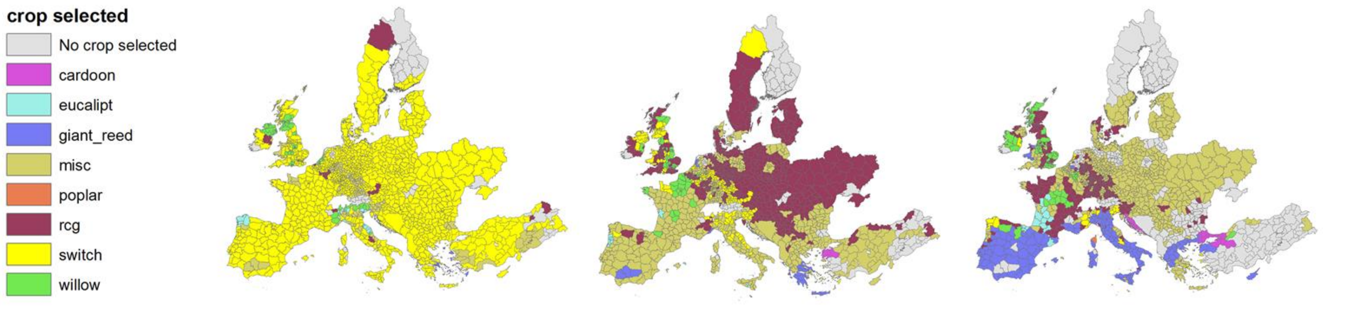
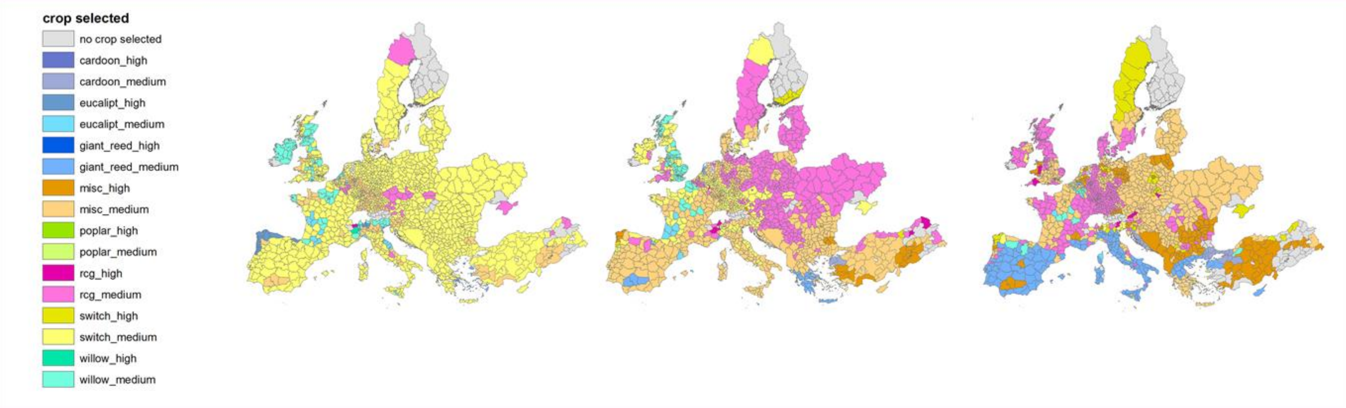


Figure 3.8 Top 3 of cheapest crop-management mixes for medium and high input systems

Rank mix medium-high Input	Crop 1	Crop 2	Crop 3



RESULTS

Perennial Biomass Potential in Europe

The results of this modelling approach will be the core database knowledge for optimum allocation, identifying the most suitable biomass crop mix for every location in Europe considering the costs. Thus, it requires an integration of several sections such as the land suitability, land availability, crop yield and production cost sections in one model or in a chain of models. In Table 3.1 selected crops are shown in percentage value according to the potentials for all countries of this study, thus, the plants as miscanthus and switchgrass (photosynthetic system C4) are the most selected crops, this to a range of adaptability and the combinations of phenological characteristics. The less selected crops are cardoon, poplar and eucalyptus. Table 3.1 shows the contribution share in mix crops selected for the three potentials and projections to the year 2020 and 2030.

Table 3.1 Summary of results for Technical, Base and UD01 Potential to the year 2012, 2020 & 2030 in low-quality land amount for 37 countries.

	Year	*misc*	*switch*	*giant_reed*	*rcg*	*cardoon*	*willow*	*poplar*	*eucalypt*	*Total Kton d.m.*
Technical potential	Pot_TECH_2012	40.2%	42.5%	8.3%	8.0%	0.2%	0.5%	0.0%	0.3%	142398
	Pot_TECH_2020	39.1%	42.0%	6.8%	9.1%	0.2%	2.1%	0.0%	0.7%	158871
	Pot_TECH_2030	38.5%	42.4%	6.5%	9.4%	0.2%	2.3%	0.0%	0.7%	160768
Base potential	Pot_BASE_2012	39.4%	42.7%	8.9%	7.8%	0.2%	0.6%	0.0%	0.4%	85926
	Pot_BASE_2020	38.0%	42.1%	6.9%	9.3%	0.1%	2.7%	0.0%	0.9%	99467
	Pot_BASE_2030	37.4%	42.4%	6.5%	9.7%	0.1%	3.0%	0.0%	0.9%	101653
UD01 (strict suitability pot)	Pot_UD01_2012	39.6%	43.3%	8.6%	7.8%	0.2%	0.3%	0.0%	0.2%	67998
	Pot_UD01_2020	37.7%	42.2%	6.7%	9.6%	0.1%	2.8%	0.0%	0.9%	82129
	Pot_UD01_2030	37.0%	42.6%	6.2%	10.0%	0.1%	3.1%	0.0%	0.9%	84906

The share of perennial biomass supply in the 37 countries in 2020 is estimated at 99.4 million tonnes dry matter and to 101.6 million tonnes dm in 2030 (Table 3.2), according to the Base Potential in Low quality released land (more detail data see Annex A.13 for UD01-2030 potential in low-quality land). Elbersen B. et al. (2013) reported 75.5 Mton (million ton) in reference scenario, while 51.6 Mton under sustainability scenario (woody and grasses crops) to EU27.

Assumptions for low quality land, the input management level Low (L1) was applied, while for high quality land, were applied input management level medium (L2) & high (L3).

Table 3.2 Total perennial biomass potential in EU and neighbouring countries [Kton dm] for the Base potential (BP) in 2020 and 2030 in low-quality released land. *Kton = kiloton

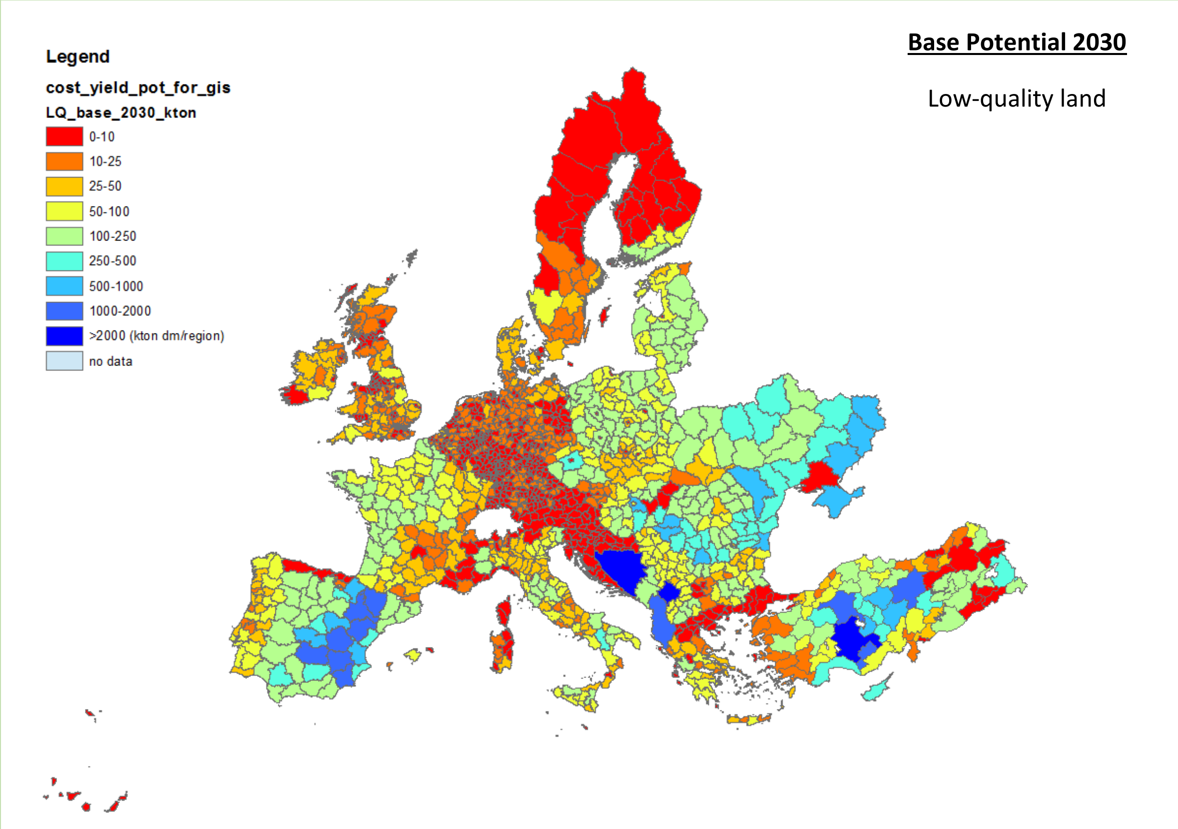
Country	Nuts0 (code)	2020	2030	Country	Nuts0 (code)	2020	2030
Albania	AL	1072	1072	Lithuania	LT	1271	1255
Austria	AT	162	166	Luxembourg	LU	20	27
Bosnia & H.	BA	3811	3755	Latvia	LV	541	563
Belgium	BE	292	379	Moldova	MD	508	508
Bulgaria	BG	2679	1921	Montenegro	ME	131	128
Cyprus	CY	263	257	R. of Macedonia	MK	791	790
Czech Republic	CZ	1083	1289	Malta	MT	10	12
Germany	DE	1588	2796	Netherlands	NL	209	363
Denmark	DK	258	244	Poland	PL	5861	6292
Estonia	EE	315	293	Portugal	PT	1201	1050
Greece	EL	1105	1139	Romania	RO	11052	11154
spain	ES	19059	19682	Serbia	RS	1723	1653
Finland	FI	389	510	Sweden	SE	342	415
France	FR	4672	5622	Slovenia	SI	9	23
Croatia	HR	74	70	Slovakia	SK	354	379
Hungary	HU	2720	2935	Turkey	TR	19127	18395
Ireland	IE	287	256	Ukraine	UA	7097	7097
Italy	IT	6057	5499	United Kingdom	UK	1360	1607
Kosovo	KS	1975	2056	***Total 37 countries***		99468	101653

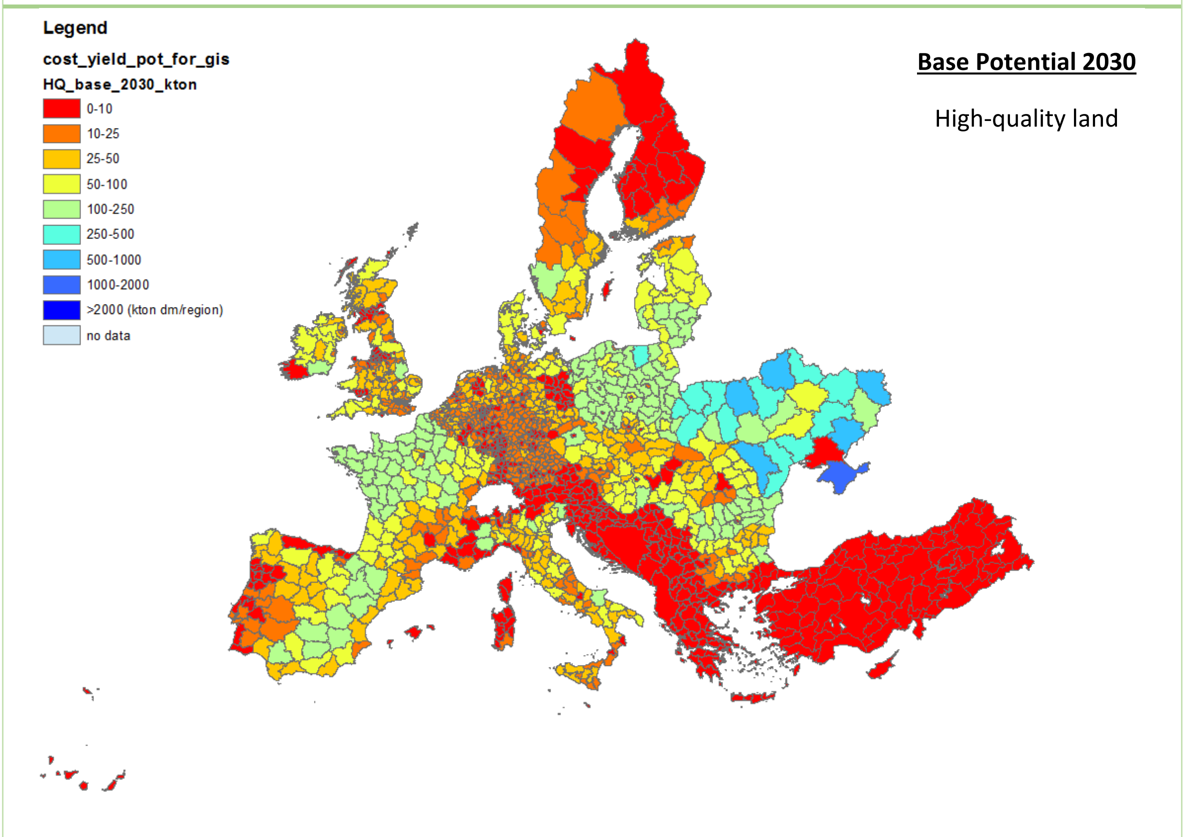
Spatial distribution of biomass potentials from perennial crops at NUTS3 level

The results of land availability potential, crop-specific suitability and yield & cost are integrated in order to estimate the potential biomass production (kton) in Europe.

In the following map the perennial biomass potential is displayed per administrative region (Nuts3 level) and the amount is expressed per unit of land (see Figure 3.9). Perennial biomass crop potentials (PBC) are largest in several regions in central Spain, Turkey, Bosnia, Bulgaria and Romania. In these regions, there are large unused land resources already since 2012. The potentials shown for 2012 are basically only pinpointing to the regions with a large unused land resource as assessed in this study based on the CAPRI land use requirements while large development of real dedicated cropping plantations for these locations have not been confirmed by cropping statistics sofar.It is therefore more interesting to look at potentials for PBC in the intermediate future 2020 (see Figure 3.9) and 2030 (see Annex A.13, for UD01-2030 potential in low quality land). The trend is towards a large increase in unused lands towards 2020 and a slight decline again towards 2030. The largest PBC are mostly found in Spain, most CEEC (Central and Eastern European Countries), western Balkans, Turkey and Ukraine. These potentials remain however most uncertain as they require serious collaboration and investments to bring abandoned agricultural lands in production again.

Figure 3.9 Biomass yields [kton] of perennials biomass crop according to land availability for Base potential to the year 2030 for low and high quality land.





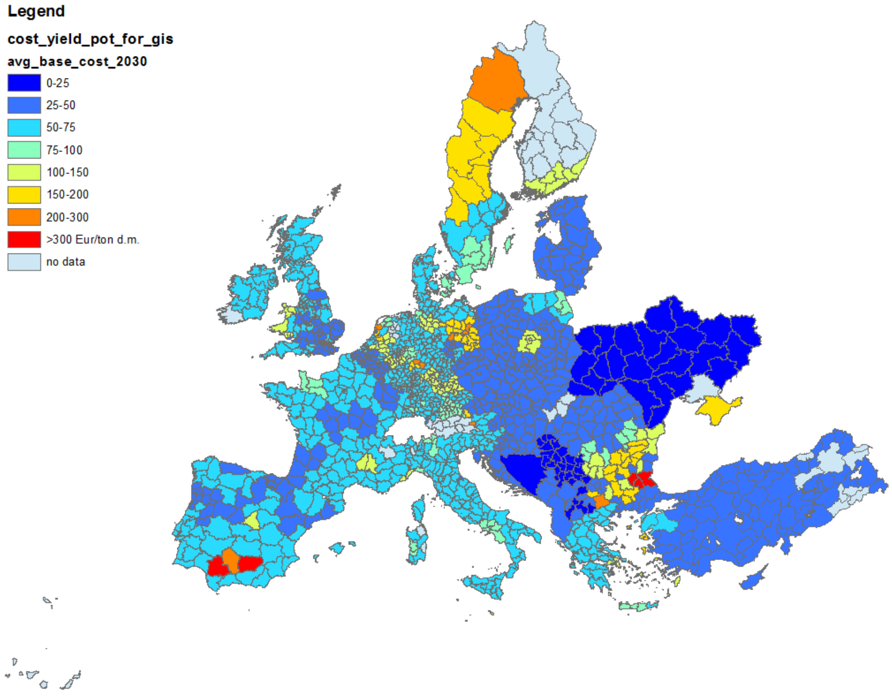
Production Cost and Potentials

All cost presented in the maps for agricultural biomass types was calculated with the Activity Based Costing (ABC) model using the output from crop yield simulation from perennial biomass (Figure 3.4, Figure 3.5). The cheapest crops are identifying and described in Figure 3.7 and Figure 3.8.

Poplar was the least popular in the selection because as compared to willow and also eucalyptus it generally delivers lower yields in the same locations. This lower yield can be explained by two phenological factors which according to the literature research presented in Chapter 2 are lower for popplar then for willow. They concern the harvest index (HI) and the Water Use Efficiency (WUE). Both factors have an important influence on the simulated yield levels which were input in the cost calculation. The result shows the cost of poplar is a slightly higher in some cases compared to willow (Annex A 1.4).

The figure 3.10 shows the average production cost of the three perennial biomass selected, for instance, according the maps for Base potential the big share are between 25-75 €/ton d.m., while the countries with cost potential more than 100 €/ton d.m. are between Romania & Bulgaria in South-Central East Europe, Sweden & Finland in North EU and Germany & Belgium in Central West EU.

Figura 3.10 Shows the average production cost (€/ton d.m.) for country of the selected mix crop in Europe and neighbouring countries for the Base potential (BP) to the year 2030.



In perennials crops cost simulation, all cost can be allocated to the final product which is the biomass such as machinery, seeds, input costs (establishment, fertilization weed, irrigation) and field harvesting costs. For instance the fraction contribution in input management L1 & L2 the establishment and fertilization sum the 73-75% of the total poduction cost, while for L3 the irrigation in some cases is greater than 75% of the total poduction cost.

In table 3.3 show the production cost for selected crops for low and high quality. The countries where there is a one NUTS3 code, the minimum and maximum is the same value (e.g. AL, LU, MD and ME). The average cost levels identified in tables in Annex A.14 shows an overview of yield-cost crop combinations for the three management levels assumed at national level, without considering land suitability.

Table 3.3 Shows the production cost minimum and maximum (€/ton d.m.) to selected mix crop in Europe for the Base potential in low and high-quality released land.

NUTS0	*Cost - High quality land*		*Costs - Low quality land*		*NUTS0*	*Cost - High quality land*		*Cost - Low quality land*	
	Min di HQ	*Max di HQ*	*Min di LQ*	*Max di LQ*		*Min di HQ*	*Max di HQ*	*Min di LQ*	*Max di LQ*
AL	234	234	32	32	LT	38	39	48	51
AT	26	182	37	335	LU	46	46	64	64
BA	102	102	24	24	LV	24	26	35	38
BE	29	42	45	68	MD	18	18	23	23
BG	30	796	33	38	ME	185	185	26	26
CY	35	35	44	44	MK	21	372	23	28
CZ	23	35	34	52	MT	87	88	115	116
DE	42	285	55	274	NL	48	166	67	273
DK	62	70	84	98	PL	23	155	31	50
EE	29	29	44	45	PT	37	60	48	66
EL	44	147	49	175	RO	33	440	36	46
ES	40	1020	44	75	RS	19	309	22	27
FI	314	678	97	443	SE	55	290	81	143
FR	41	217	51	94	SI	50	59	72	91
HR	21	26	26	30	SK	21	25	29	36
HU	31	34	36	40	TR	32	1996	30	51
IE	51	55	72	80	UA	16	285	19	29
IT	45	112	52	129	UK	39	91	53	149
KS	197	197	29	29					

CONCLUSION

The potentials resulting from the analyses in which land availability is combined with crop performance potential in terms of yields and cost shows that indeed there is a large potential for dedicated crops in many regions in Europe at very varying cost levels.

For low-quality land the dedicated biomass crop potential amounts to 67 and 101 Mton d.m. respectively for the year 2020 and 2030 for the whole of Europe. There is a large unused land resource already since 2012 but the mobilisation of this potential is only just starting.

In terms of crop mix, results also show that miscanthus, switchgrass and giant reed are the most attractive crops as they can provide highest yields with lowest costs in unused lands in most regions of Europe. The results of this study are a good basis for getting an initial understanding of the type of crops that are most suited to be used for starting dedicated cropping plantations is all regions in Europe.

The results presented here confirm that interesting yields at acceptable cost can be reached with perennials crops in unused lands in most regions in Europe. The regions with the cheapest crop potentials are South and Central East EU. Thus, there are regions that have a higher potential for affordable dedicated cropping potentials and these regions are mostly concentrated in CEEC, western Balkan countries and certain southern European regions as long as precipitation levels are high enough (>600 mm/year) and stable.

This study also provides a good overview of cost that need to be made to produce the biomass with different crop mixes in different regions in Europe. This information can be helpful making initial calculations of the economic feasibility of setting up biomass delivery chains based on dedicated cropped biomass and where regions are with lowest production cost.

This study simulated a potential amount of biomass calculated on the availability of land for perennial biomass crops. The approach taken in this study took account of biophysical conditions, production cost and crop yield performance for as far as information is available on the phenological characteristics of the crops and field trial performance.

There are however several factors which have not or unsufficiently been addressed in this study and therefore the results of this study should be interpreted with care and can gain from further research work in the future:

1) Although the activity based costing model developed in S2BIOM allows for highly detailed cost calculations and national variations in main input cost have been taken into account, it remains an impossible task to cover the wide diversity of harvest and collection practices in Europe. Cost calculations made in S2BIOM need to be regarded as average cost which in reality can still range very strongly between countries and regions.
2) It should be realised that the cost calculated here only cover the road side cost. These are only part of the cost and one should realize that still many cost needs to be made to bring the biomass from the road side to the gate of the conversion plant. So to get a full picture of the at gate cost, more information is required which is chain and location specific and requires additional tools and information.
3) Activities related to establishing the contract (transaction costs) and other overheads are not (yet) accounted for. These costs can be quite substantial.
4) Cost are calculated here only indicate towards the minimal price that needs to be paid to cover the cost of the residues. In reality, there are also biomass types, such as for cereal straw, that have already a large market demand. The road side cost are then less meaningful while the real price setting is to obtain a good idea about cost that need to be made to buy the feedstock.

Evaluation of crop yield and cost production in different regions and on a large scale are one option for the provisioning of feedstock for the large European ambitions for a biobased economy aimed at decarbonising the economy. Large-scale production of dedicated perennial biomass crops is still very limited in Europe. To mobilise the unused land potential in Europe a clear stimulation and regulation policy needs to be developed to also come to a sustainable production of biomass. However, for the mobilisation of this potential policy stimulation and regulation is necessary.

The study presented here showed what the implications would be for applying widely the RED sustainability criteria. It actually confirms that if these criteria are applied strictly, like is the case in the base potential, there is still a very large biomass resource that can be produced on unused lands.

The difference to the year 2030 between the Technical and the Base potential in which land is constrained by RED criteria leads to a reduction in the potential of 33.8% as compared to the Technical potential. The difference between Base and the more strict user defined potential is 11 %. The influence on the crop mix is smaller, but small differences between the potentials (see Table 3.1).

However, at this moment there is practically no market demand for dedicated perennial biomass Mobilising this type of biomass on unused lands while at the same time ensuring that RED criteria are met and indirect adverse effects on land use and biodiversity are avoided requires additional policy measures. First, financial incentives are needed for stimulation of dedicated cropping on unused lands provided it can be verified that these lands are indeed not needed for food production and their conversion does not lead to loss of ecosystem services. Second, more effort needs to be put into the development of advanced biofuels and other highly efficient lignocellulosic biomass conversion technologies to increase the market demand.

There is also need for improvement in the technologies for breeding, managing and collecting and processing all the dedicated biomass efficiently. Complex logistical arrangements are required to bring the usually bulky biomass sources together, and to increase the energy densities at the plant gate. Furthermore, joint and organised action at a regional level is required to set up stable biomass delivery chains, including local policy support and planning permission.

General Conclusions

from abandoned to recovered land through the deployment of resilient biomass crops

Main conclusions

Although much work has already been done on studying yielding capacity and soil and management combinations of perennial biomass crops in Europe in field trials a full extrapolation of the yielding capacity of these different crops for the whole of Europe has not been made before. The same applies to the cost of producing biomass with perennials. Cost estimates are still scarce and many cost factors are challenging to estimate particularly at regional levels for all countries in Europe. In this respect the work presented here is novel. The results can give guidance to the choice of crop management combinations in different regions. The conclusions are referring to the main outcomes of the work presented in Chapters 1, 2 and 3.

Unused land availability in Europe

Our assessment showed that in spite of the fact that land is a scarce resource world wide, there are still many lands in Europe that remain unused and that are potentially available for the production of biomass with dedicated crops.

The starting point of the assessment made here was that agricultural land that remains unused now or in the future because they are not required for food and feed production anymore and can be regarded as ‘potential lands’ for biomass production for non-food uses. The reason for leaving lands out of food and feed production is usually because yields reached are too low and cost do not meet the market prices paid for the conventional agricultural products farmers produce. There are more reason however, but in this study in which CAPRI market model output was used as a starting point for the post-model assessment, this is the key starting point. From the CAPRI baseline calculations, it becomes apparent that this abandonment of land by agriculture is expected to be quite significant particularly in certain regions in central and southern Europe where land uses in 2010 are significantly larger than in certain regions in 2020 and 2030.

In EU28 the Total Polygon Area is 422.4 Mha, that is covering in average around 40% of UAA. Besides Non-EU countries considered have 161.4 Mha total polygon area where the UAA cover in average around 50%. The result of unused land show in *Technical potential* for EU28-2030 has about 19.9 Mha. Meanwhile, *Base potential* shows the RED criteria effect (reduction land, e.g. exclude protected area) thus, the prevention of the loss of highly biodiversity areas or areas with high carbon stocks are not used for dedicated cropping was made. In this way, it is possible to estimate the amount of land availability for *Base potential* for EU28-2030 has about 15.2 Mha. The low-quality land category as land most sustainable to produce perennial biomass crop and high-quality land is expected to be used again for feed and food agriculture. The countries with the largest amount of unused land in the low-quality category are Spain, Romania, Poland, France and Italy.

Suitable crop mix per region

The suitable area depends primarily on crop agroclimatic and biophysical request. The result of land suitability show map-mask generated at NUTS3 level resolution, that indicates the suitable/unsuitable according to biophysical variables. From the perspective of suitability Climate, the crops present a wide range of adaptability in the wider EU and neighbouring countries, are miscanthus and switchgrass. In some cases, the suitable land for a specific crop is larger than expected, this may be due to the parameters considered, which were limited by the database, but serves as a basis for future estimates and simulations. Suitability from attainable yield perspective, the high variability of distribution shows the difference in adaptation between selected crops. Suitability from cost perspective, that can be drawn is that irrigation is not likely to be economically feasible in most perennial plantations and therefore likely to be less of an environmental threat too. It implies however, that if dedicated cropping is to take place in southern Europe there is an evident need to find perennial crops and varieties that are strongly drought tolerant and water use efficient.

Final potential for dedicated crops

The study presented here showed what the implications would be for applying widely the RED sustainability criteria. It actually confirms that if these criteria are applied strictly, like is the case in the base potential, there is still a very large biomass resource that can be produced on unused lands. The difference to the year 2030 between the Technical and the Base potential in which land is constrained by RED criteria leads to a reduction in the potential of 33.8% as compared to the Technical potential. The difference between Base and the more strict user defined potential is 11 %. The potential of perennial biomass supply in the 37 countries in Base Potential is estimated at 101.6 million tonnes d.m. in low-quality released land. Furthermore, the projections for 2030 for perennial biomass crop would be mostly found in central Spain, Turkey, Romania, Poland, France and Italy. In these regions, there are large unused land resources already since 2012.

The identification of the best mix crop in terms of yield and cost level, for the countries with the future higher availability of land for the dedicated crops were switchgrass, miscanthus, giant reed and cardoon in Mediterranean area, while under North Europe condition were obtained by RCG, willow, switchgrass, miscanthus.

Limitations of the study and recommendations for further research

Although the work performed delivers already some interesting observations, the results of the yield and cost level estimations for the different dedicated crops can certainly be further improved in methodology and data inputs in the future:

i. The experience with growing biomass crops in Europe is still limited and crop simulation input data were mostly based on field trial information from a limited number of locations. The yield simulation work done in this project was based on data available, but much more experience and field trailing is necessary to obtain more reliable crop yield response understanding, particularly in more marginal circumstances in Europe. Estimates of cost and yields for dedicated biomass crops should be based as much as possible on larger scale field experiences in the relevant bio-climatic circumstances. The more field experience there is, the more reliable yield estimates can be made for the whole European territory using crop yield simulation models.

ii. In this study, no attention was paid to performance differences for different varieties of the same crop. For the crop simulation work crop phenological parameters were taken that refer to an average crop performance not taking account of all variety characteristics that may exist. The simple assumption was made that the crop used in every region was chosen according to best performing varieties of the crop. So for example, for southern Finland a switchgrass variety was chosen that proved to be best surviving in cold winters and short growing season.

iii. Since there is still relatively limited experience in Europe with producing these crops the costing of growing these crops is also rather immature. The experiences with specific field activities and also the machinery available are still limited and in development. Exact knowledge on management of the dedicated cropping systems can be improved when field experience is further incorporated in the cost calculation.

iv. Currently limited cost are assumed for the preparation of the field before establishing the crop, while this could be very challenging in lands that have gone out of production for a longer period of time and/or are marginal or low productive. This aspect certainly needs further investigation.

In additions to the limitations in data and experience it is also very challenging to make reliable predictions on the mobilisation of dedicated crops on unused lands. Currently lignocellulosic and SRC crop production areas are very small. Whether the potential from these crops will really be mobilized depends on many factors which were not completely taken into account in the assessment of the potentials for dedicated crops. Some of the main factors determining future mobilization are summarized underneath:

- Access rights to lands;
- Uncertainty about establishment cost, particularly on the more marginal lands
- Uncertainty about economic returns as experience with growing these novel biomass crops is very limited and is mostly in the stage of field trials. Some European wide scattered commercial experiences exist which sofar have not been proven very successful (e.g. RCG production in Finland). Uncertainty about economic returns is influencing the interest of land owners and/or investors;
- Loss of flexibility by the farmer to decide on his/her cultivation plan as the plantations usually have a lifetime of between 10 to 20 years
- Unclear arrangements regarding CAP payment rights in certain EU countries when agricultural land is planted with SRC crops for a longer period of time
- Opportunity to set-up optimal logistical biomass delivery chains making collection cost effective requires cooperation between different actors in the supply chain not only several biomass providers (farmers), but also the conversion industries
- Ensure minimal feedstock delivery and security of supply which can only be realized if several farmers together invest in dedicated biomass cropping activities in one region.
- Ensure that no other (currently unidentified) ecosystem service are lost when converting the land into a perennial biomass plantation
- Ensure that GHG mitigation potential of the full chain biomass delivery chain in which the dedicated biomass is used is large enough to compensate for the several fossil alternatives. This requires a full GHG lifecycle assessment for concrete biomass delivery chains taking the wide diversity of biobased energy and materials that can be generated into account.
- Most of these factors were not taken into consideration because they are difficult to predict.

5. ACKNOWLEDGMENT

This study was funded by the S2BIOM EU project no. FP7-608622.

University of Bologna (UniBO) and Institute of Advanced Studies – Bologna (ISA)

6. REFERENCES of Literature Database

AEBIOM, (2013). European Bioenergy Outlook 2013: statistical report. Available at: http://www.greenpartnerships.eu/wp/wp-content/uploads/AEBIOM_European-Bioenergy-Outlook-2013-Copy.pdf.

Alexopoulou, E., Christou, M., & Eleftheriadis, I. (2010). Role of 4F cropping in determining future biomass potentials , including sustainability and policy related issues. A publication as part of the Biomass Futures project (IEE 08 653 SI2. 529 241) funded by the European Union's Intelligent Energy Programme. Pp. 1-40.

Alexopoulou, E., Sharma, N., Papatheohari, Y., Christou, M., Piscioneri, I., Panoutsou, C., & Pignatelli, V. (2008). Biomass yields for upland and lowland switchgrass varieties grown in the Mediterranean region. *Biomass and Bioenergy*, *32*(10), pp. 926–933.

Alexopoulou, E., Zanetti, F., Scordia, D., Zegada-Lizarazu, W., Christou, M., Testa, G., Monti, A. (2015). Long-Term Yields of Switchgrass, Giant Reed, and Miscanthus in the Mediterranean Basin. *BioEnergy Research*, *8*(4), pp. 1492–1499.

Allen R, Pereira L, Raes D, Smith M, (1998) Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements - Fao Irrigation and Drainage Paper 56. FAO, Rome.

Allen G., R. et al., (2006). Evapotranspiración del cultivo: Guias para la determinación de los requerimientos de agua de los cultivos. *FAO :Estudios FAO Riego y Drenaje 56,* p.297.

Allen, B., Kretschmer, B., Baldock, D., Menadue, H., Nanni, S., & Tucker, G. (2014). Space for energy crops – assessing the potential contribution to Europe's energy future. Report produced for BirdLife Europe, European Environmental Bureau and Transport & Environment., (May), p. 69.

Amichev, B. Y., Hangs, R. D., & Van Rees, K. C. J. (2011). A novel approach to simulate growth of multi-stem willow in bioenergy production systems with a simple process-based model (3PG). *Biomass and Bioenergy*, *35*(1), pp. 473–488.

Anderson, E., Arundale, R., Maughan, M., Oladeinde, A., Wycislo, A., Voigt, T., Maughan, M. (2011). Growth and agronomy of Miscanthus x giganteus for biomass production Growth and agronomy of Miscanthus x giganteus for biomass production, *7269*(January), pp. 167–183.

Angelini, L. G., Ceccarini, L., Nassi o Di Nasso, N., & Bonari, E. (2009a). Comparison of Arundo donax L. and Miscanthus x giganteus in a long-term field experiment in Central Italy: Analysis of productive characteristics and energy balance. *Biomass and Bioenergy*, *33*(4), pp. 635–643.

Angelini, L. G., Ceccarini, L., Nassi o Di Nasso, N., & Bonari, E. (2009b). Long-term evaluation of biomass production and quality of two cardoon (Cynara cardunculus L.) cultivars for energy use. *Biomass and Bioenergy*, *33*(5), pp.810–816.

Arnoult, S. & Brancourt-Hulmel, M. (2015). A Review on Miscanthus Biomass Production and Composition for Bioenergy Use: Genotypic and Environmental Variability and Implications for Breeding. *Bioenergy Research*, 8(2), pp.502–526.

Bacher, W., & Sauerbeck, G. (2001). Giant Reed (Arundo donax L.) Network Improvement biomass quality Final report FAIR-CT-96-2028. *Braunschweig Bundesforschungsanstalt Für Landwirtschaft (FAL).*

Barbanti, L., Grandi, S., Vecchi, A., & Venturi, G. (2006). Sweet and fibre sorghum (Sorghum bicolor (L.) Moench), energy crops in the frame of environmental protection from excessive nitrogen loads. *European Journal of Agronomy*, *25*(1), pp. 30–39.

Bassam, E. (2010). Handbook of bioenergy crops: a complete reference to species, development and applications. Earthscan, London, UK. pp. 1- 545.

Britz, W. and Witzke, H.-P. (eds.) 2011. *CAPRI Model Documentation 2008*: Version 2. Bonn, Institute for Food and Resource Economics, University of Bonn. (available at http://www.capri-model.org/docs/capri_documentation.pdf)

Capros P, De Vita A,Tasios N, Papadopoulos D, Siskos P, Apostolaki E, Zampara M, Paroussos J, Fragiadakis K, Kouvaritakis N, Höglund-Isaksson L, Winiwarter W, Purohit P, Böttcher H, Frank S, Havlík P, Gusti M, Witzke HP (2013): EU Energy, Transport amd GHG Emissions Trends to 2050 - Reference Scenario 2013.

CAPRI website at: http://www.capri-model.org/dokuwiki/doku.php

Ceulemans, R., McDonald, a. J. S., & Pereira, J. S. (1996). A comparison among eucalypt, poplar and willow characteristics with particular reference to a coppice, growth-modelling approach. *Biomass and Bioenergy*, *11*(2–3), pp. 215–231.

Christian, D., Riche, A., & Yates, N. (2008). Growth, yield and mineral content of Miscanthus x giganteus grown as a biofuel for 14 successive harvests. *Industrial Crops and Products*, *28*(3), pp. 320–327.

Christou, M., Mardikis, M., Alexopoulou, E., Cosentino, S. L., Copani, V., & Sanzone, E. (2003). Environmental studies on Arundo Donax. *8th International Conference on Environmental Science and Technology Lemnos Island, Greece, 8 – 10 September 2003*, (September), pp. 102–110.

Clifton-brown, J., Breuer, J., & Jones, M. B. (2007). Carbon mitigation by the energy crop, Miscanthus. *Global Change Biology*, *13*(11), pp. 2296–2307.

Cosentino, S. L., Copani, V., Patanè, C., Mantineo, M., & D'Agosta, G. M. (2008). Agronomic, energetic and environmental aspects of biomass energy crops suitable for Italian environments.

Italian Journal of Agronomy, *3*(2), pp. 81–95.

Cosentino, S. L., Patanè, C., Sanzone, E., Copani, V., & Foti, S. (2007). Effects of soil water content and nitrogen supply on the productivity of Miscanthus x giganteus Greef et Deu. in a Mediterranean environment. *Industrial Crops and Products*, *25*(1), pp. 75–88.

Cunniff, J., Purdy, S. J., Barraclough, T. J. P., Castle, M., Maddison, A. L., Jones, L. E, Shield, F., Karp, A. (2015). High yielding biomass genotypes of willow (Salix spp.) show differences in below ground biomass allocation. *Biomass and Bioenergy*, *80*(0), pp. 114–127.

Curt, M. D., Fernandez, J., & Martinez, M. (1995). Productivity and Water Use Efficiency of Sweet Sorghum (Sorghum Bicolor (L .) Moench) CV. "Keller" in Relation to water Regime, *8*(6), pp. 401–409.

Dallemand, E. J. F., Petersen, J. E., & Karp, A. (2008). Short Rotation Forestry , Short Rotation Coppice and perennial grasses in the European Union : Agro-environmental aspects , present use and perspectives. *JRC Scientific and Technical Reports*, (October 2007), 166.

Danalatos, N. G., Archontoulis, S. V., & Mitsios, I. (2007). Potential growth and biomass productivity of Miscanthus X giganteus as affected by plant density and N-fertilization in central Greece. *Biomass and Bioenergy*, *31*(2–3), pp. 145–152.

DEFRA. (2007). Planting and Growing Miscanthus. *DEFRA. Crops for Energy Branch*, (July), pp. 1–19.

Dees, M., Elbersen, B., Fitzgerald, J., Vis, M., Anttila, P., Forsell, N., Ramirez-Almeyda, J., García Galindo, D., Glavonjic, B., Staritsky, I., Verkerk, H., Prinz, R., Monti, A., Leduc, S., Höhl, M., Datta, P., Schrijver, R., Sergey Zudin, Lindner, M., Lesschen, J. & Diepen, K. (2017a): D1.6 A spatial data base on sustainable biomass cost-supply of lignocellulosic biomass in Europe - methods & data sources. Project Report. S2BIOM – a project funded under the European Union 7th Framework Programme for Research. Grant Agreement n°608622. Chair of Remote Sensing and Landscape Information Systems, Institute of Forest Sciences, University of Freiburg. p.174 . http://www.s2biom.eu/en/publications-reports/s2biom.html

Dees, M., Elbersen, B., Fitzgerald, J., Vis, M., Anttila, P., Ramirez-Almeyda, J., Glavonjic, B., Staritsky, I., Verkerk, H., Monti, A., Datta, P., Schrijver, R., Lindner, M. & Diepen, K. (2017b): D1.1 Roadmap for regional end-users on how to collect, process, store and maintain biomass supply data. Project Report. S2BIOM – a project funded under the European Union 7th Framework Programme for Research. Grant Agreement n°608622. Chair of Remote Sensing and Landscape Information Systems, Institute of Forest Sciences, University of Freiburg. p.78 . http://www.s2biom.eu/en/publications-reports/s2biom.html

Dees, M., Elbersen, B., Fitzgerald, J., Vis, M., Anttila, P., Forsell, N., Ramirez-Almeyda, J., Glavonjic, B., Staritsky, I., Verkerk, H., Prinz, R., Leduc, S.,.Datta, P., Lindner, M., Zudin, S., Höhl, M (2017c) Atlas with regional cost supply biomass potentials for EU 28, Western Balkan Countries, Moldavia, Turkey and Ukraine. Project Report. S2BIOM – a project funded under the European Union 7th Framework Programme for Research. Grant Agreement n°608622. Chair of Remote Sensing and Landscape Information Systems, Institute of Forest

Sciences, University of Freiburg. p.103

Dillen, S.Y. et al., 2013. Biomass yield and energy balance of a short-rotation poplar coppice with multiple clones on degraded land during 16 years. *Biomass and Bioenergy*, 56, pp.157–165.

Doorenbos, J. and W.O. Pruitt. 1977. Crop water requirements. FAO Irrigation and Drainage Paper No. 24. Food and Agric. Organiz. of the U.N. Rome

Dufossé, K., Drewer, J., Gabrielle, B., & Drouet, J. L. (2014). Effects of a 20-year old Miscanthus × giganteus stand and its removal on soil characteristics and greenhouse gas emissions. *Biomass and Bioenergy*, *69*, pp.198–210.

Dragoni, F. et al., 2015. Aboveground Yield and Biomass Quality of Giant Reed (Arundo donax L.) as Affected by Harvest Time and Frequency. *Bioenergy Research*, 8(3), pp.1321–1331.

ESDB v2.0: "The European Soil Database distribution version 2.0, European Commission and the European Soil Bureau Network, CD-ROM, EUR 19945 EN, 2004".

Elbersen, H., Bakker, R., & Elbersen, B. (2005). A Simple Method To Estimate Practical Field Yields Of Biomass Grassess in Europe, *14th* European Biomass Conference, 17–21 October 2005. Paris.

Elbersen, W., Poppens, R., & Bakker, R. (2013). Switchgrass (Panicum virgatum L.) A perennial biomass grass for efficient production of feedstock for the biobased economy. *NL Agency*, 28.

Elbersen, W., E. alakangas, B. Elbersen, E. Annevelink, J. Ramirez-Almeyda, T. Lammens. 2016. S2Biom project WP2 (D2.4) Explanatory note accompanying the database for standardized biomass characterization. Project Report. S2BIOM – a project funded under the European Union 7th Framework Programme for Research. Grant Agreement n°608622. http://www.s2biom.eu/en/publications-reports/s2biom.html

Elbersen B.S. & Staritsky, I. (2016). Guidelines for data collection to estimate and monitor technical and sustainable biomass supply. Deliverable 2.2 of the Biomass Policies project.

Elbersen, B., I. Staritsky, G. Hengeveld, M.J. Schelhaas, H. Naeff, H. Böttcher 2012. Atlas of EU biomass potentials. Deliverable 3.3: Spatially detailed and quantified overview of EU biomass potential taking into account the main criteria determining biomass availability from different sources. Biomass Futures.

Elbersen B.S., Uwe Fritsche, Jan-Erik Petersen Jan Peter Lesschen, Hannes Böttcher & Koen Overmars. (2013). Assessing the effect of stricter sustainability criteria on EU biomass crop potential*. Modelling and Analysis. Biofuels, Bioproducs & Biorefining. pp 173 - 192.

Eliasson, A., Jones, R. J. a, Nachtergaele, F., Rossiter, D. G., Terres, J. M., Van Orshoven, J., van Velthuizen, H., Bottcher, K., Haastrup, P., Le Bas, C. (2010). Common criteria for the redefinition of Intermediate Less Favoured Areas in the European Union. *Environmental Science and Policy*, *13*(8), pp.766–777

Eurostat, (2015). Regions in the European Union: Nomenclature of territorial units for statistics NUTS 2013 / EU-28 ISSN 2363.

EU (2007). The Impact of a Minimum 10% Obligation for Biofuel Use in the EU-27 in 2020 on Agricultural Markets, Vol. AGRI G-2/WM D, p. 10. European Commission, Brussels.

EEA (2007). Estimating the environmentally compatible bioenergy potential from agriculture. European Environment Agency (EEA). Technical report No 12/2007. p. 134.

ETCSIA, (2012). European Topic Centre on Spatial Information and Analysis: Corine Land Cover 2006 Raster Data.

ETC/SIA, (2013). Review of the EU bioenergy potential from a resource efficiency perspective. *Background report to EEA study. Alterra, Wageningen*. p.305

Erickson, J. E., Soikaew, A., Sollenberger, L. E., & Bennett, J. M. (2012). Water Use and Water-Use Efficiency of Three Perennial Bioenergy Grass Crops in Florida. *Agriculture*, *2*(4), pp.325–338.

Evans, L.T., Fischer, R.A., (1999). Yield potential: its definition, measurement and significance. Crop Sci, 39, pp. 1544-1551.

Fiorese, G. & Guariso, G., (2010). A GIS-based approach to evaluate biomass potential from energy crops at regional scale. *Environmental Modelling and Software*, 25(6), pp.702–711.

Fagnano, M., Impagliazzo, a., Mori, M., & Fiorentino, N. (2015). Agronomic and Environmental Impacts of Giant Reed (Arundo donax L.): Results from a Long-Term Field Experiment in Hilly Areas Subject to Soil Erosion. *Bioenergy Research*, *8*(1), pp.415–422.

FAO. (2012). Sintesis de los Informes Nacionales de Progreso, 24° Reunion de la Comision International del Alamo, Dehradun, India 30 Octubre - 2 de Noviembre 2012.

Fazio, S., & Barbanti, L. (2014). Energy and economic assessments of bio-energy systems based on annual and perennial crops for temperate and tropical areas. *Renewable Energy*, *69*, pp. 233–241.

Fernandez, J. (2009). El Cultivo de Cardo (Cynara cardunculus L.) para la produccion de biomassa. *Hojas Divulgativas*, *n. 2130 HD*, pp. 1–44.

Fernandez, J., Curt, M. D., & Aguado, P. L. (2006). Industrial applications of Cynara cardunculus L. for energy and other uses. *Industrial Crops and Products*, *24*(3), pp. 222–229.

Garofalo, P., & Rinaldi, M. (2013). Water-use efficiency of irrigated biomass sorghum in a Mediterranean environment. *Spanish Journal of Agricultural Research*, *11*(4), pp.1153–1169.

Guidi, W., Piccioni, E., & Bonari, E. (2008). Evapotranspiration and crop coefficient of poplar and willow short-rotation coppice used as vegetation filter. *Bioresource Technology*, *99*(11), pp. 4832–4840.

van der Hilst, F. et al., (2010). Potential, spatial distribution and economic performance of regional biomass chains: The North of the Netherlands as example. *Agricultural Systems*, 103(7), pp.403–417. Available at: http://dx.doi.org/10.1016/j.agsy.2010.03.010.

Hickman, G. C., Vanloocke, A., Dohleman, F. G., & Bernacchi, C. J. (2010). A comparison of canopy evapotranspiration for maize and two perennial grasses identified as potential bioenergy crops. *GCB Bioenergy*, *2*(4), pp. 157–168.

Irmak, S. et al., (2013). Evapotranspiration crop coefficients for mixed riparian plant community and transpiration crop coefficients for Common reed, Cottonwood and Peach-leaf willow in the Platte River Basin, Nebraska-USA. *Journal of Hydrology*, 481, pp.177–190.

Hope, H., & McELROY, A. (1990). Low-temperature tolerance of switchgrass (Panicum virgatum L.), pp. 1091–1096.

Jones, R., Le-Bas, C., Nachtergaele, F., Rossiter, D., Orshoven, J. Van, Schulte, R., & Velthuizen, H. Van. (2013). Updated common bio-physical criteria to define natural constraints for agriculture in Europe. Definition and scientific justification for the common criteria. *JRC Science and Policy Reports. EUR 26638 EN*, 68.

Kahle, P., Beuch, S., Boelcke, B., Leinweber, P., & Schulten, H. R. (2001). Cropping of Miscanthus in Central Europe: Biomass production and influence on nutrients and soil organic matter. *European Journal of Agronomy*, *15*(3), pp. 171–184.

Kandel, T. P., Hastings, A., Jorgensen, U., & Olesen, J. E. (2016). Simulation of biomass yield of regular and chilling tolerant Miscanthus cultivars and reed canary grass in different climates of Europe. *Industrial Crops and Products*, *86*, pp. 329–333.

Katerji, N., Mastrorilli, M., & Rana, G. (2008). Water use efficiency of crops cultivated in the Mediterranean region: Review and analysis. *European Journal of Agronomy*, *28*(4), pp. 493–507.

Kretschmer, B., Alexopoulou, E., & Panoutsou, C. (2012). Mapping the biomass crops options in 2020 and 2030 in EU27. Biomass Futures Project. *CRES (Centre for Renewable Energy Sources). D6.4 - WP6*, (July 2011). Retrieved from http://www.4fcrops.eu/

Lado, L.R., Hengl, T. & Reuter, H.I., 2008. Heavy metals in European soils: A geostatistical analysis of the FOREGS Geochemical database. *Geoderma*, 148(2), pp.189–199.

Lamboni, M., Koeble, R. & Leip, A., (2016). Multi-scale Land-use disaggregation modelling : concept and application to EU Countries. *Environmental Modelling & Software*, under revi, pp.183–217.

Larsen, S., Jørgensen, U., Kjeldsen, J. B., & Lærke, P. E. (2014). Long-Term Miscanthus Yields Influenced by Location, Genotype, Row Distance, Fertilization and Harvest Season. *Bioenergy Research*, *7*(2), pp. 620–635.

Lasorella, M. V. (2014). Suitability of Switchgrass (*Panicum virgatum* L.) Cultivars in Mediterranean Agroecosystems. *Ph.D. Dissertation, Scuola Superiore Sant'Anna*.

Lasorella, M. V., Monti, A., Alexopoulou, E., Riche, A., Sharma, N., Cadoux, S., van diepen K., Elbersen B., Atzema A.J., Elbersen, H. W. (2011). Yield comparison between switchgrass and miscanthus based on multi-year side by side comparison in europe. Conference: 9th European Biomass Conference and Exhibition, 6-10 June 2011, Berlin, Germany

Lesschen, J.P., van den Berg, M., Westhoek, H.J., Witzke, H.P., Oenema, O., 2011. Greenhouse gas emission profiles of European livestock sectors. Animal Feed Science and Technology 166–167, pp. 16-28.

Lewandowski, I., & Heinz, A. (2003). Delayed harvest of miscanthus - Influences on biomass quantity and quality and environmental impacts of energy production. *European Journal of Agronomy*, *19*(1), pp. 45–63.

Lewandowski, I., Clifton-Brown, J. & Murphy-Bokern, D., (2015). Perennial biomass Crops for a Resource-Constrained world. Biomass 2015 Summary. , (Stuttgart-Hohenheim, Germany 7-10 September), pp.1–31. Available at: www.biomass2015.eu

Lewandowski, I., Scurlock, J. M. O., Lindvall, E., & Christou, M. (2003). The development and current status of perennial rhizomatous grasses as energy crops in the US and Europe. *Biomass and Bioenergy*, *25*(4), pp. 335–361.

Lord, R. a. (2015). Reed canarygrass (Phalaris arundinacea) outperforms Miscanthus or willow on marginal soils, brownfield and non-agricultural sites for local, sustainable energy crop production. *Biomass and Bioenergy*, *78*, pp. 110–125.

Lovett, A. a. et al., (2009). Land use implications of increased biomass production identified by gis-based suitability and yield mapping for miscanthus in england. *Bioenergy Research*, 2(1–2), pp.17–28.

Mantineo, M., D'Agosta, G. M., Copani, V., Patanè, C., & Cosentino, S. L. (2009). Biomass yield and energy balance of three perennial crops for energy use in the semi-arid Mediterranean environment. *Field Crops Research*, *114*(2), pp. 204–213.

Monti, A., & Zegada-Lizarazu, W. (2015). Sixteen-Year Biomass Yield and Soil Carbon Storage of Giant Reed (Arundo donax L.) Grown Under Variable Nitrogen Fertilization Rates. *Bioenergy Research*.

Monti, A. et al., 2015. What to harvest when? Autumn, winter, annual and biennial harvesting of giant reed, miscanthus and switchgrass in northern and southern Mediterranean area. *Industrial Crops and Products*, 75, pp.129–134.

Mueller, L., Behrendt, A., Schalitz, G., & Schindler, U. (2005). Above ground biomass and water use efficiency of crops at shallow water tables in a temperate climate. *Agricultural Water Management*, *75*(2), pp. 117–136.

Nassi o Di Nasso, N., Roncucci, N., Triana, F., Tozzini, C., & Bonari, E. (2011). Productivity of giant reed (Arundo donax L.) and miscanthus (Miscanthus x giganteus greef et deuter) as energy crops: Growth analysis. *Italian Journal of Agronomy*, *6*(3), pp. 141–147.

Nocentini, A., Di Virgilio, N. & Monti, A., 2015. Model Simulation of Cumulative Carbon Sequestration by Switchgrass (Panicum Virgatum L.) in the Mediterranean Area Using the DAYCENT Model. *Bioenergy Research*, 8(4), pp.1512–1522.

Nsanganwimana, F., Pourrut, B., Mench, M., & Douay, F. (2014). Suitability of Miscanthus species for managing inorganic and organic contaminated land and restoring ecosystem services. A review. *Journal of Environmental Management*, *143*, pp. 123–134.

Paris, P. & Nahm, M., (2014). A Modern Response To Global Challenges of Climate Change , Food Production , Bioenergy Needs , Environmental Restoration. AGROCOP CONFERENCE 16-17 OCTOBER.

Perpiña Castillo, C. et al., 2015. Modelling the spatial allocation of second-generation feedstock (lignocellulosic crops) in Europe. *International Journal of Geographical Information Science*, 29(10), pp.1807–1825.

Phyllis2, database for biomass and waste, https://www.ecn.nl/phyllis2, Energy research Centre of the Netherlands.

Price, L., Bullard, M., Lyons, H., Anthony, S., & Nixon, P. (2004). Identifying the yield potential of Miscanthus x giganteus: An assessment of the spatial and temporal variability of M. x giganteus biomass productivity across England and Wales. *Biomass and Bioenergy, 26*(1), pp. 3–13.

Ragab Ragab, (2014). A note on water use efficiency and water productivity. Water4Crops Project - WP3. Integrating Bio-Treated Wastewater Reuse with Enhanced Water Use Efficiency to Support the Green Economy in EU and India. CEH, UK. http://www.water4crops.org/water-use-efficiency-water-productivity-terminology/

Sahramaa, M., Ihamaki, H., & Jauhiainen, L. (2003). Variation in biomass related variables of reed canary grass. *Agricultural and Food Science in Finland*, *12*(3–4), pp. 213–225.

Schrijver Raymond et al., 2016. Calculating the cost of lignocellulosic non-food biomass sources. Athens. DLO-Alterra. Session 2: Estimation of biomass availability for lignocellulosic biomass. S2Biom summer school, Athens, Greece, 17-20 May, 2016.

Steduto P, Hsiao TC, Raes D, Fereres E (2009) AquaCrop—The FAO crop model to simulate yield response to water: i Concepts and underlying principles. Agronomy Journal, 101, pp. 426–437.

Steduto, P., Hsiao, T. C., Fereres, E., & Raes, D. (2012). *Crop yield response to water. Irigation and Drainage Paper 66. AQUACROP*.

Stričević, R., Dželetović, Z., Djurović, N., & Cosić, M. (2015). Application of the AquaCrop model to simulate the biomass of Miscanthus x giganteus under different nutrient supply conditions. *GCB Bioenergy*, *7*(6), pp. 1203–1210.

Sugiura, A. (2009). WATERRENEW: WASTEWATER POLISHING USING RENEWABLE ENERGY CROPS. *Cranfield University, School of Applied Sciences, Ph.D. Dissertation*.

Surendran Nair, S. et al., (2012). Bioenergy crop models: Descriptions, data requirements, and future challenges. *GCB Bioenergy*, 4(6), pp.620–633.

Terres, JM. Hagyo, A. Wania A. (Eds.), Confalonieri R., Jones, B. Van Diepen K. & Van Orshoven J. (2014). Scientific contribution on combining biophysical criteria underpinning the delineation of agricultural areas affected by specific constraints. Methodology and factsheets for plausible criteria combinations. JRC Science and Policy Report EUR 26940 EN. pp. 1-81

Triana, F., Nassi o Di Nasso, N., Ragaglini, G., Roncucci, N., & Bonari, E. (2014). Evapotranspiration, crop coefficient and water use efficiency of giant reed (Arundo donax L.) and miscanthus (Miscanthus X giganteus Greef et Deu.) in a Mediterranean environment. *GCB Bioenergy*, pp.811–819.

Taylor G. et al., (2016). Bioenergy Trees. Genetic and Genomic strategies to improve yield. Book title Perennial Biomass Crops for a Resource-Constrained World. Springer 2016. p. 313

Velthof, G.L., Oudendag, D., Witzke, H.P., Asman, W.A.H., Klimont, Z., Oenema, O., (2009). Integrated assessment of nitrogen emissions from agriculture in EU-27 using MITERRA-EUROPE-EUROPE Journal of Environmental Quality 38, pp. 402-417.

Zatta, A., (2013). Soil Organic Carbon Dynamics Under Perennial Energy Crops. *Doctoral Thesis. Bologna University*, pp.1–91.

Zatta, A., Clifton-Brown, J., Robson, P., Hastings, A., & Monti, A. (2014). Land use change from C3 grassland to C4 Miscanthus: Effects on soil carbon content and estimated mitigation benefit after six years. *GCB Bioenergy*, *6*(4), pp. 360–370.

Zegada-Lizarazu, W., Elbersen, W., Cosentino, S. L., Zatta, A., Alexopoulou, E., & Monti, A. (2010). Agronomic aspects of future energy crops in Europe. *Biofuels, Bioproducts and Biorefining*.

Zegada-Lizarazu, W., Parrish, D., Berti, M., & Monti, A. (2013). Dedicated crops for advanced biofuels: Consistent and diverging agronomic points of view between the USA and the EU-27. *Biofuels, Bioproducts and Biorefining*.

Zub, H.W. & Brancourt-Hulmel, M., (2010). Review article Agronomic and physiological performances of different species of Miscanthus, a major energy crop. A review. *Agron. Sustain. Dev.*, 30, pp.201–214.

Web link:

- http://eusoils.jrc.ec.europa.eu/library/ESDAC/Index.html
- http://esdac.jrc.ec.europa.eu/content/esdac-map-viewer#tabs-0-description=0
- http://eusoils.jrc.ec.europa.eu/SOER2010/StateTrends.html
- http://esdac.jrc.ec.europa.eu/content/soil-ph-europe
- http://esdac.jrc.ec.europa.eu/content/european-soil-database-derived-data
- http://www.eea.europa.eu/data-and-maps/figures/sensitivity-to-desertification-index-map
- http://www.agmip.org/6th-agmip-global-workshop-side-sessions/
- http://ec.europa.eu/environment/nature/natura2000/db_gis/index_en.htm
- http://marswiki.jrc.ec.europa.eu/agri4castwiki/index.php/Weather_Monitoring
- http://publications.jrc.ec.europa.eu/repository/bitstream/JRC101873/lb-aw-16-002-en-n.pdf
- http://agri4cast.jrc.ec.europa.eu/DataPortal/Index.aspx
- http://mars.jrc.ec.europa.eu/mars/About-us/AGRI4CAST

7. LIST OD PUBBLICATIONS CONNECT WITH THE THESIS

- Dees, M., Elbersen, B., Fitzgerald, J., Vis, M., Anttila, P., **Ramirez-Almeyda, J.,** Glavonjic, B., Staritsky, I., Verkerk, H., Monti, A., Datta, P., Schrijver, R., Lindner, M. & Diepen, K. (2017): D1.1 Roadmap for regional end-users on how to collect, process, store and maintain biomass supply data. Project Report S2BIOM. Chair of Remote Sensing and Landscape Information Systems, Institute of Forest Sciences, University of Freiburg. 78 p. http://www.s2biom.eu/en/publications-reports/s2biom.html
- Dees, M., Elbersen, B., Fitzgerald, J., Vis, M., Anttila, P., Forsell, N., **Ramirez-Almeyda, J**., García Galindo, D., Glavonjic, B., Staritsky, I., Verkerk, H., Prinz, R., Monti, A., Leduc, S., Höhl, M., Datta, P., Schrijver, R., Sergey Zudin, Lindner, M., Lesschen, J. & Diepen, K. (2017): D1.6 A spatial data base on sustainable biomass cost-supply of lignocellulosic biomass in Europe - methods & data sources. Project Report S2BIOM. Chair of Remote Sensing and Landscape Information Systems, Institute of Forest Sciences, University of Freiburg. 174 p. http://www.s2biom.eu/en/publications-reports/s2biom.html
- Elbersen, W., E. alakangas, B. Elbersen, E. Annevelink, **J. Ramirez-Almeyda**, T. Lammens. 2016. S2Biom project WP2 (D2.4) Explanatory note accompanying the database for standardized biomass characterization. Project Report. S2BIOM – a project funded under the European Union 7th Framework Programme for Research. Grant Agreement n°608622. http://www.s2biom.eu/en/publications-reports/s2biom.html
- Dees, M., Elbersen, B., Fitzgerald, J., Vis, M., Anttila, P., Forsell, N., **Ramirez-Almeyda, J.**, Glavonjic, B., Staritsky, I., Verkerk, H., Prinz, R., Leduc, S., Datta, P., Lindner, M., Zudin, S., Höhl, M (2017): D1.8 Atlas with regional cost supply biomass potentials for EU 28, Western Balkan Countries, Moldavia, Turkey and Ukraine. Project Report S2BIOM. Chair of Remote Sensing and Landscape Information Systems, Institute of Forest Sciences, University of Freiburg. 103 p. (will be published).
- **Ramirez-Almeyda J**., Andrea Monti, Berien Elbersen, Igor Staritsky, Calliope Panoutsou, Raymond Schrijver, Wolter Elbersen. Book “Modeling and Optimization of Biomass Supply Chains”. Chapter 9: Assessing the potentials for non- food crops. (will be submit)
- Elbersen B., Forsell N., Leduc S., Staritsky I., Witzke P. & **Ramirez-Almeyda J**., Book “Modeling and Optimization of Biomass Supply Chains”. Chapter 2, Existing modelling platforms for biomass supply in Europe: inputs, outputs and projection potentials. (will be submit)

LIST OF PUBBLICATIONS IN CONGRESS AND CONFERENCES

- Oral presentation. **J. Ramirez Almeyda**. “Assessment of the cropping potential and the development of dedicated crops database”. S2Biom Project Summer School. National Technical University of Athens (NTUA). 17-20 May 2016. Athens, Greece.
- Oral presentation. **J. Ramirez Almeyda**, A. Monti, N. Di Virgilio, B. Elbersen, I. Staritsky. “Integrated approach for sustainable allocation of biomass crops in Europe”. XLIV Convegno Nazionale Società Italiana Di Agronomia (SIA). Dal 14-16 settembre 2015. Bologna, Italia.
- EUBCE 2015. M. Dees, B. Elbersen, M. Lindner, A. Monti, P. Anttila, N. Forsell, M. Vis, H. Gallaun, D. Borota, B. Cosic, P. Datta, N. Di Virgilio, A. Eryasar, J. Fitzgerald, B. Gabrielle, D. Garcia Galindo, B. Glavonjic, N. Krajnc, S. Leduc, C. Panoutsou, D. Pantic**, J. Ramirez Almeyda**, M. Schardt, D. Stojiljkovic, L. Wenzelides, T. Zheliezna. 2014. “Establishment of lignocellulose cost- supply potential database for EU 28 and neighbor region at NUTS3 level”. European Biomass conference and exhibition. 01-04 June 2015, Wien.

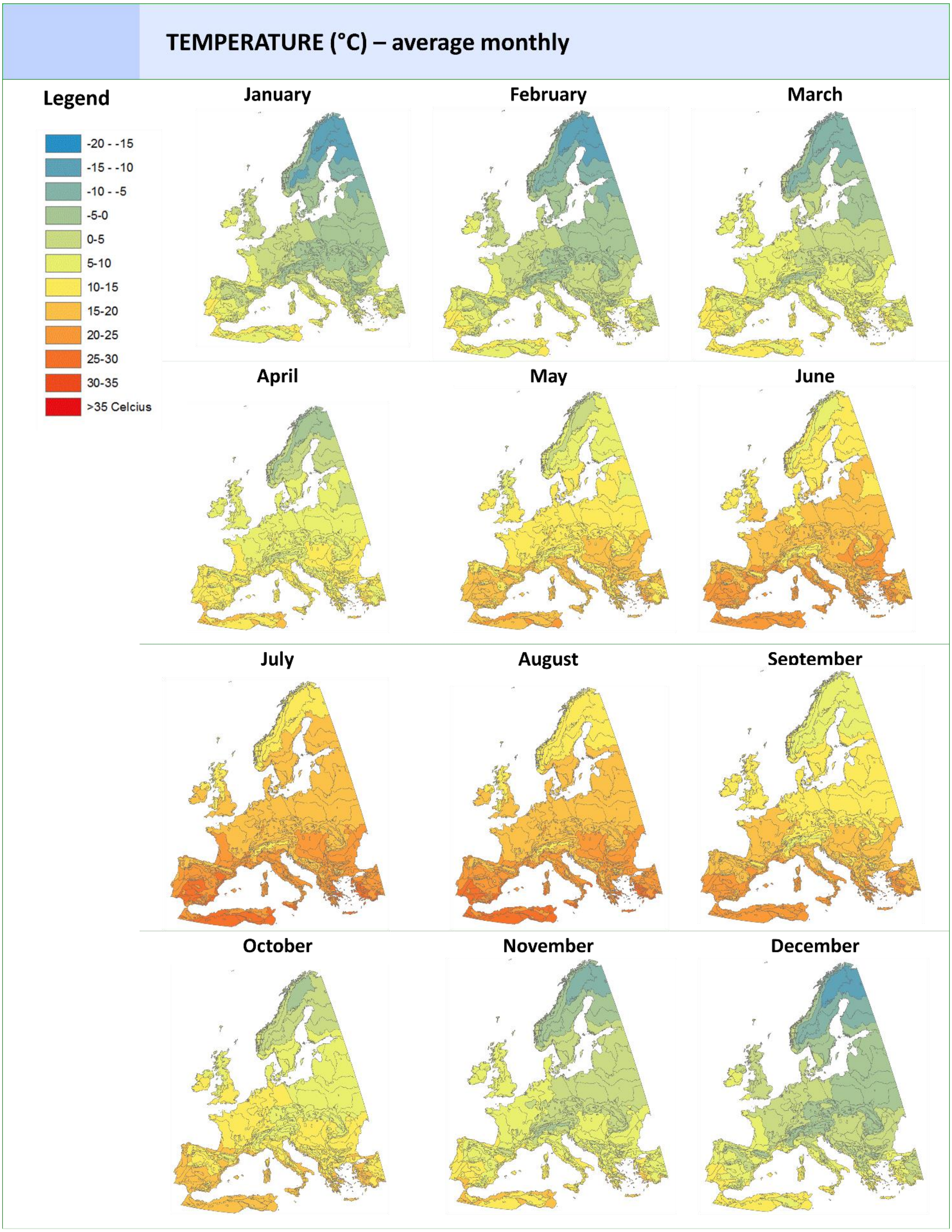
Annex A.1: Utilized agricultural area and CAPRI result for unused land by country in 1000ha

		Year 2010				Year 2020				Year 2030			
Country Nuts0	***Total polygon country area (1000 ha)***	***UAA***	***Fallow***	***Released land (med./low Q)***	***Released land (good Q)***	***UAA***	***Fallow***	***Released land (med./low Q)***	***Released land (good Q)***	***UAA***	***Fallow***	***Released land (med./low Q)***	***Released land (good Q)***
AL	2878.6	1225.2	197.6	138.3		1214.0	210.7	147.5		1234.3	210.8	147.5	
AT	8394.4	3125.7	2.8	1.7		3180.8	0.4	57.7	57.4	3112.3	1.5	57.9	57.0
BA	5121.2	2168.3	517.5	362.3		2211.8	517.2	362.1		2219.3	509.7	356.8	
BE	3066.7	1408.4	6.9	5.7		1427.0	5.0	59.9	55.9	1428.5	2.1	81.8	80.1
BG	11099.5	5056.4	184.3	129.8	12.8	5241.8	180.8	254.7	131.9	5176.8	110.1	203.7	129.4
CY	924.9	164.1	20.7	9.9		167.0	23.4	13.4	2.2	164.8	24.2	11.8	0.2
CZ	7887.4	4063.7	139.7	109.5		4089.2	95.1	145.2	69.2	4033.2	120.0	164.6	67.9
DE	35749.3	17244.6	16.0	13.3		17325.1	1.8	370.3	368.9	17268.2	4.1	650.9	647.4
DK	4316.7	2718.0	0.2	0.2		2661.9	0.3	61.9	61.6	2661.2	0.1	58.7	58.6
EE	4533.8	836.7	31.6	24.5	4.0	831.6	31.7	60.2	35.7	831.6	29.4	56.0	33.2
EL	13202.7	4278.1	381.2	142.0		4294.7	252.9	126.0	32.5	4299.6	290.3	112.9	6.0
ES	50598.3	25348.9	2973.1	1479.0		25952.4	2453.1	1606.2	377.3	25954.3	2475.0	1693.3	458.7
FI	33754.7	2341.5	245.0	154.8		2391.5	152.2	160.1	63.2	2391.5	207.0	186.8	54.1
FR	63804.7	29224.9	170.1	136.9		29495.4	177.7	659.9	515.6	29365.4	144.6	867.0	748.6
HR	5642.9	1378.2	14.0	11.6	1.4	1352.2	11.9	8.3		1352.3	11.3	7.9	
HU	9301.3	5749.7	288.5	205.7		5791.3	260.6	359.3	173.9	5756.8	291.2	365.2	157.7
IE	6994.6	4316.1	0.4	0.4		4264.6	0.1	92.5	92.4	4179.3	0.3	82.1	81.9
IT	30057.8	13942.2	314.8	221.9		14121.2	314.7	733.3	511.3	13761.7	295.5	653.1	445.7
KS	1090.7	606.7	309.3	216.5	0.0	594.0	341.8	239.2		608.6	355.8	249.0	0.0
LT	6489.9	2957.2	99.5	84.5		2972.8	82.7	244.9	174.7	2972.7	68.3	255.4	197.4
LU	259.5	114.9	0.1	0.1		123.1	0.1	5.0	4.9	121.6	0.0	7.0	6.9
LV	6458.6	1903.4	63.5	51.7		1924.6	60.9	87.8	38.2	1914.8	56.6	98.2	52.2
MD	3385.5	1940.0		151.7	151.7	1940.0		151.7	151.7	1940.0		151.7	151.7
ME	1388.2	510.3	18.2	13.2	0.2	497.7	19.6	13.7		503.7	19.1	13.4	
MK	2543.3	1264.8	130.9	91.6		1274.0	127.1	89.0		1283.2	126.9	88.8	
MT	31.5	10.9	0.5	0.8		10.5	0.6	0.5		10.5	0.7	0.6	
NL	3737.9	1923.4	2.2	2.0		1946.5	0.8	51.6	50.8	1946.5		91.5	91.5
PL	31192.8	16734.6	536.4	410.2		17052.9	298.0	1187.7	960.6	17052.9	235.5	1349.2	1166.0
PT	9188.7	3234.5	334.8	149.8		3174.1	195.5	113.0	25.1	3114.3	157.7	106.1	34.4
RO	23836.8	13879.0	1292.2	882.0		14108.2	1027.9	1108.7	407.6	14063.9	1075.8	1112.5	389.9
RS	7748.5	4892.7	240.9	168.6		4896.7	295.1	206.6		4989.8	283.0	198.1	
SE	44971.8	3104.0	11.7	8.7		3105.7	1.8	98.8	97.4	3105.7	6.0	117.3	112.7
SI	2026.7	494.5	0.4	0.2		497.9	0.3	3.7	3.6	508.3	0.2	9.5	9.4
SK	4902.6	2187.9	36.6	28.4		2146.9	27.1	51.7	30.7	2116.3	26.8	58.4	38.1
TR	77205.6	38208.9	3148.9	2204.2	0.0	39141.8	3353.7	2347.6	0.0	38874.0	3204.3	2243.0	0.0
UA	60105.7	28676.7	980.1	1608.1	1608.1	28676.7	980.1	1608.1	1608.1	28676.7	980.1	1608.1	1608.1
UK	24457.4	16053.0	16.0	14.3		16120.5	22.6	285.0	264.9	16120.6	15.7	348.9	335.1
Total	***608351.1***	***264733.3***	***12726.7***	***9233.9***	***1778.2***	***267663.5***	***11525.2***	***13172.6***	***6367.1***	***266560.8***	***11339.6***	***13864.7***	***7220.0***

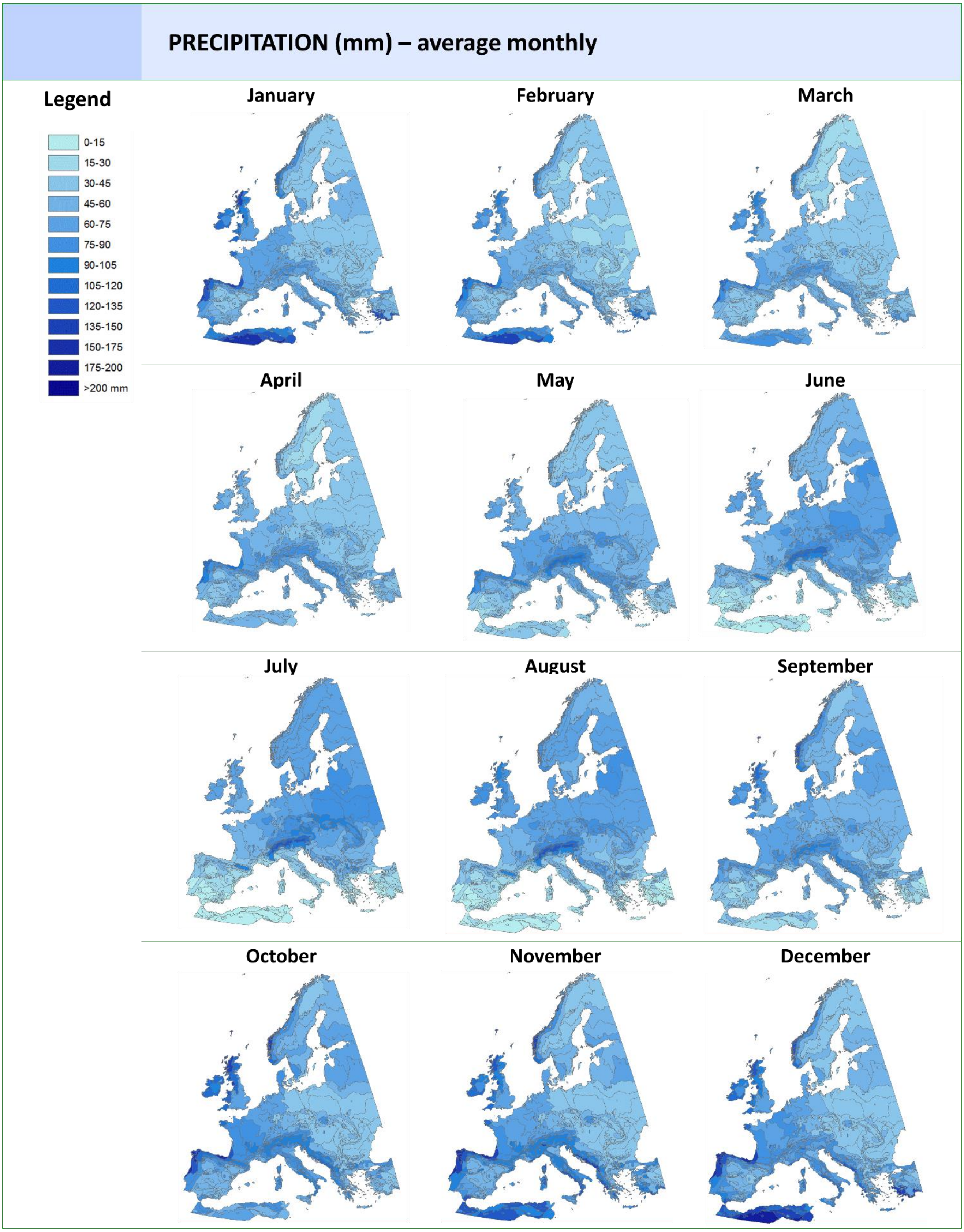
Annex A.2 Results of Land availability for the three potential S2Biom by country in 1000ha.

	Technical potential (1000ha)						*Base potential (1000ha)*						*Strict Suitability Potential (UD01) - (1000ha)*					
	Year 2010		*Year 2020*		*Year 2030*		*Year 2010*		*Year 2020*		*Year 2030*		*Year 2010*		*Year 2020*		*Year 2030*	
Nuts0	*LQ*	*HQ*	*LQ*	*HQ*	*LQ*	*HQ*	*LQ*	*HQ*	*LQ*	*HQ*	*LQ*	*HQ*	*LQ*	*HQ*	*LQ*	*HQ*	*LQ*	*HQ*
AL	336		358		358		168		179		179		158		169		169	
AT	4.5		58	57	59	57	2.6		29	28	29	28	1.0		28	28	28	28
BA	880		879		866		440		440		433		414		414		408	
BE	13		65	56	84	80	11		56	48	72	69	4.9		52	48	70	69
BG	314	13	435	132	314	129	226	8.9	302	91	217	89	151	8.9	218	91	141	89
CY	31		37	2,2	36	0.2	20		24	1.4	23	0.2	18		22	1.4	22	0.2
CZ	249		240	69	285	68	213		209	60	249	59	110		127	60	144	59
DE	29		372	369	655	647	24		315	312	554	547	11		313	312	550	547
DK	0.3		62	62	59	59	0.3		59	59	56	56	0.2		59	59	56	56
EE	56	4.0	92	36	85	33	52	3.7	85	33	79	31	23	3.7	56	33	52	31
EL	523		379	32	403	6.0	260		191	19	200	3.5	225		169	19	174	3.5
ES	4452		4059	377	4168	459	2924		2682	239	2758	290	2365		2252	239	2348	290
FI	400		312	63	394	54	370		288	58	364	50	322		147	58	245	50
FR	307		838	516	1012	749	257		713	441	863	640	117		565	441	742	640
HR	26	1.4	20		19		13	0.7	10		10		5.8	0.7	4.2		4.0	
HU	494		620	174	656	158	393		497	143	526	130	234		329	143	375	130
IE	0.8		93	92	82	82	0.8		87	87	77	77	0.3		87	87	77	77
IT	537		1048	511	949	446	396		774	377	700	329	192		572	377	516	329
KS	526		581		605	0.0	263		290		302	0,0	247		273		285	0
LT	184		328	175	324	197	166		296	158	292	178	76		221	158	231	178
LU	0.3		5.1	4.9	7.0	6.9	0.2		3.9	3.8	5.5	5.4	0.1		3.9	3.8	5.4	5.4
LV	115		149	38	155	52	104		134	35	140	47	47		79	35	89	47
MD	152	152	152	152	152	152	76	76	76	76	76	76	76	76	76	76	76	76
ME	31	0.2	33		32		16	0.1	17		16		15	0.1	16		15	
MK	223		216		216		111		108		108		105		102		102	
MT	1.2		1.1		1.2		1.1		1.0		1.1		0.7		0.5		0.5	
NL	4.2		52	51	91	91	3.9		47	45	81	81	1.8		46	45	0.9	81
PL	947		1486	961	1585	1166	747		1180	768	1264	934	324		946	768	1078	934
PT	485		309	25	264	34	262		171	15	148	20	216		138	15	72	20
RO	2174		2137	408	2188	390	1569		1545	306	1564	293	1358		1194	306	1228	293
RS	409		502		481		205		251		241		84		103		99	
SE	20		101	97	123	113	19		94	91	115	106	8.2		93	91	110	106
SI	0.5		3.9	3.6	10	9.4	0.2		1.4	1.3	3.5	3.4	0.1		1.3	1.3	3.4	3.4
SK	65		79	31	85	38	49		61	24	66	30	21		40	24	46	30
TR	5353	0.0	5701	0.0	5447	0.0	2677	0.0	2851	0.0	2724	0.0	2287	0.0	2457	0.0	2352	0.0
UA	2588	1608	2588	1608	2588	1608	1294	804	1294	804	1294	804	1245	804	1245	804	1245	804
UK	30		308	265	365	335	29		293	251	347	318	14		256	251	315	318
Total	***21961***	***1778***	***24698***	***6367***	***25204***	***7220***	***13361***	***893***	***15653***	***4575***	***16178***	***5295***	***10478***	***893***	***12875***	***4575***	***13472***	***5295***
Total by year	***23739***		***31065***		***32424***		***14254***		***20228***		***21473***		***11371***		***17449***		***18767***	

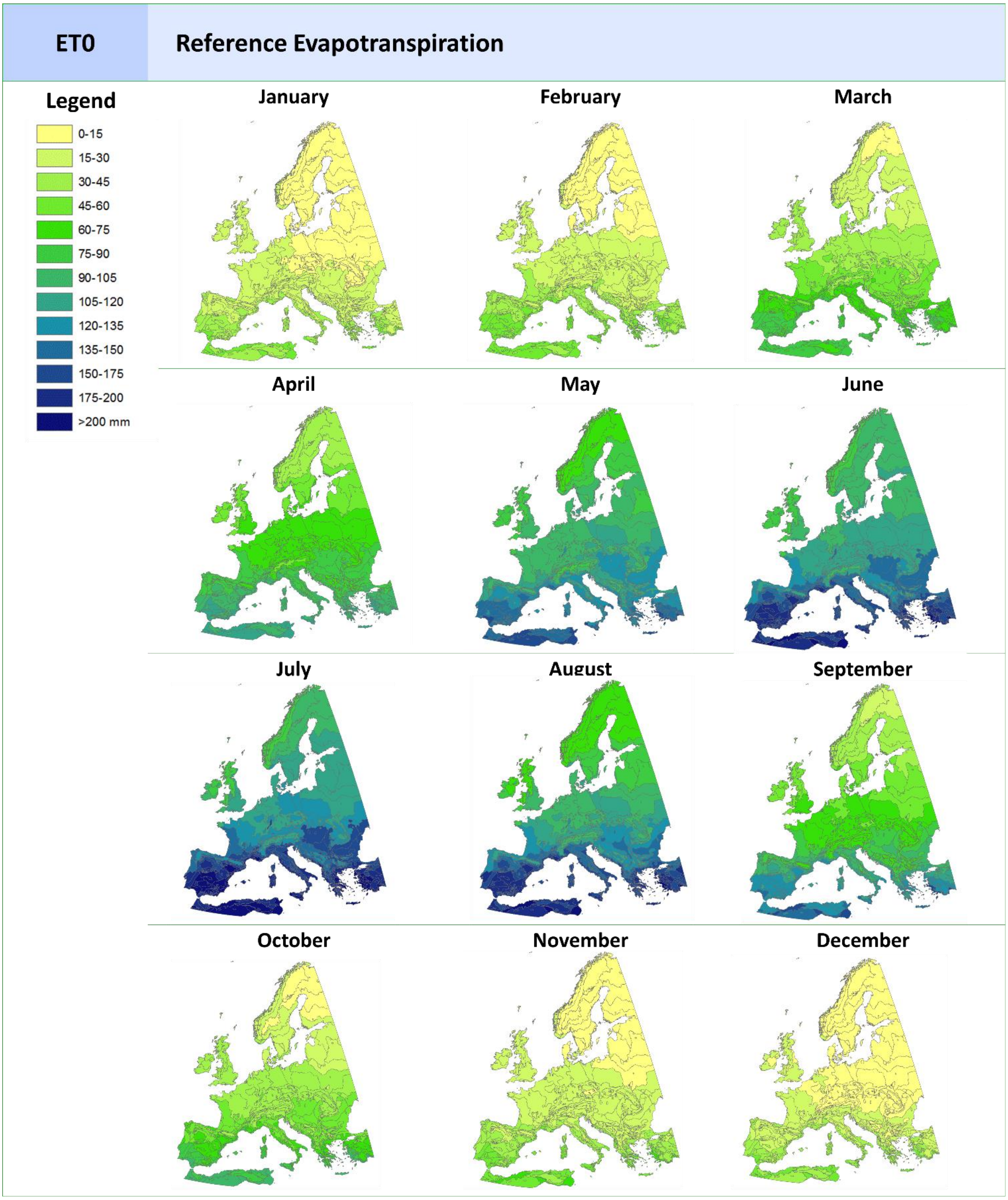
Annex A.3 Average **Temperature** (°C) in EU28. Combination of distribution in Agro-Environmental zone - AEZ (Metzger et al. 2015) and MARS climatic database average (JRC) by month. ***Source***: Maps produced by UniBO and Alterra/WUR



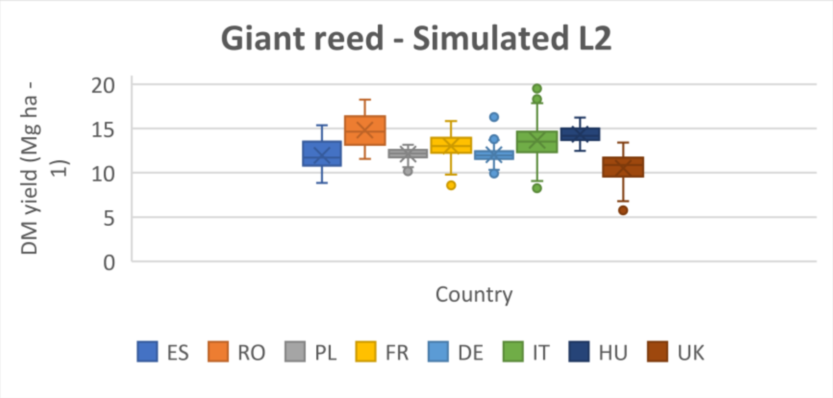
Annex A.4 Average **precipitation** (mm) in EU28. Combination of distribution in Agro-Environmental zone -AEZ (Metzger et al. 2015) and MARS climatic database average (JRC) by month.

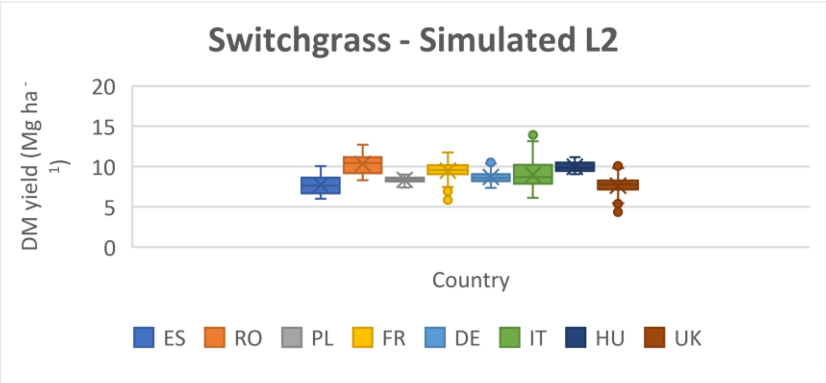


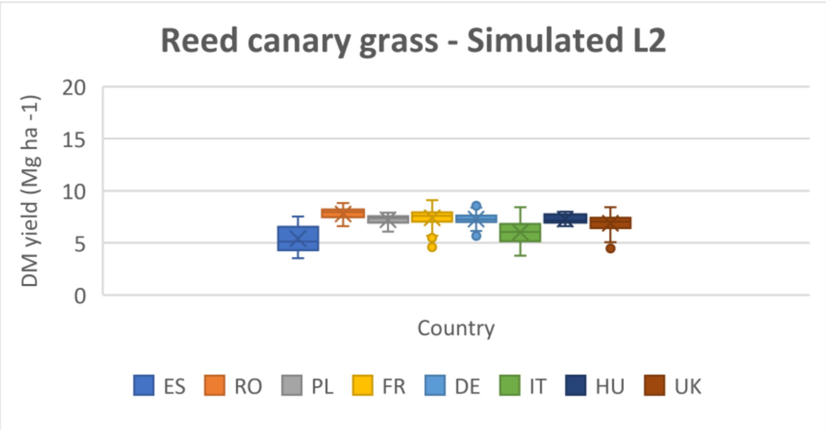
Annex A.5 Average **Reference Evapotranspiration** (mm) in EU28. ET_0 data was determined from the Penman-Monteith method equation (Allen *et al.*, 1998) by JRC. The figure show combination of, distribution in Agro-Environmental zone- AEZ (Metzger et al. 2015) and MARS climatic database Average (JRC) by month.

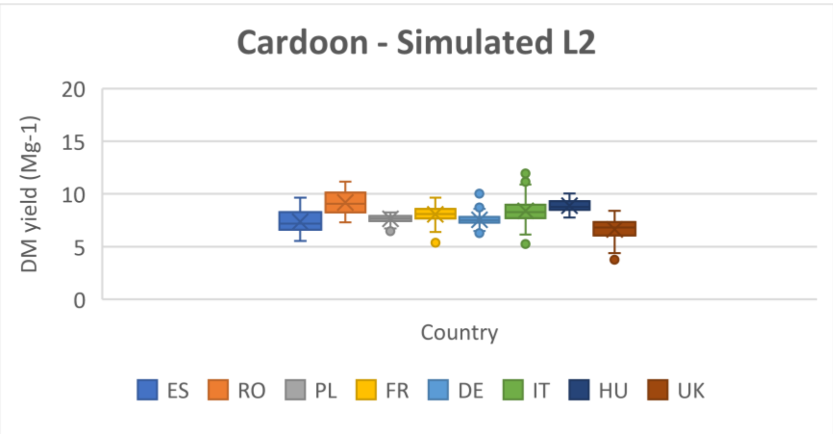


Annex A.6 Simulated crop yield potential (input level 2) for giant reed, switchgrass, RCG and cardoon in the 8 countries with the highest surface of unused land in the 2030 scenario.

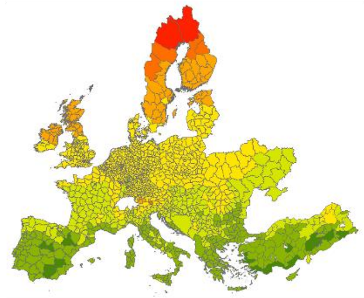
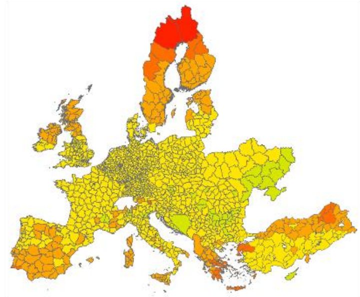
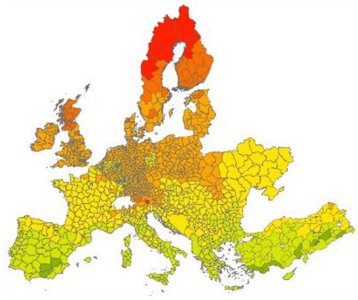
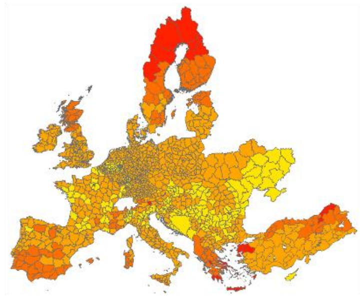
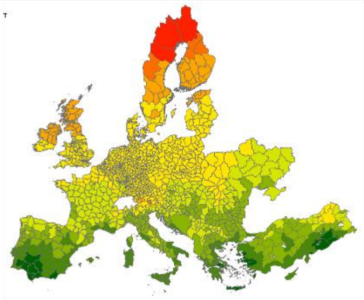
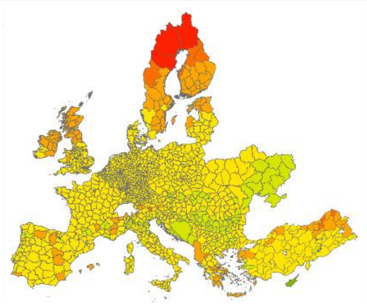
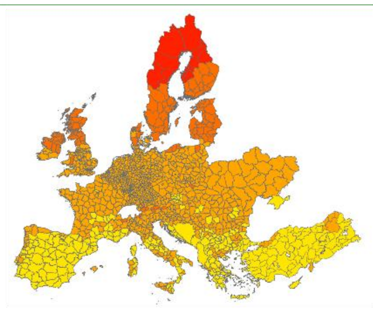
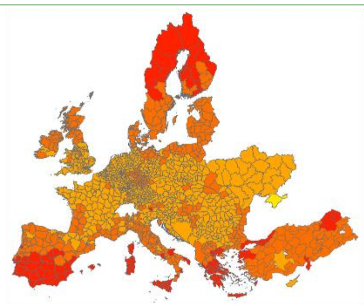
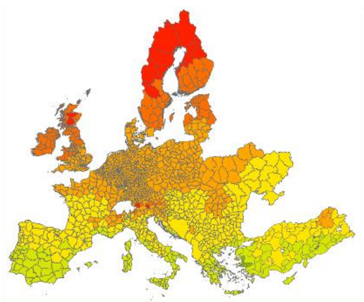
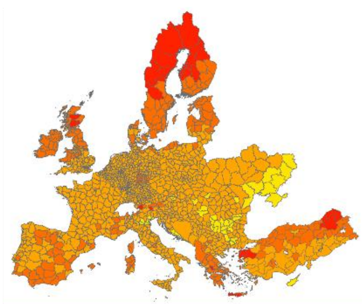




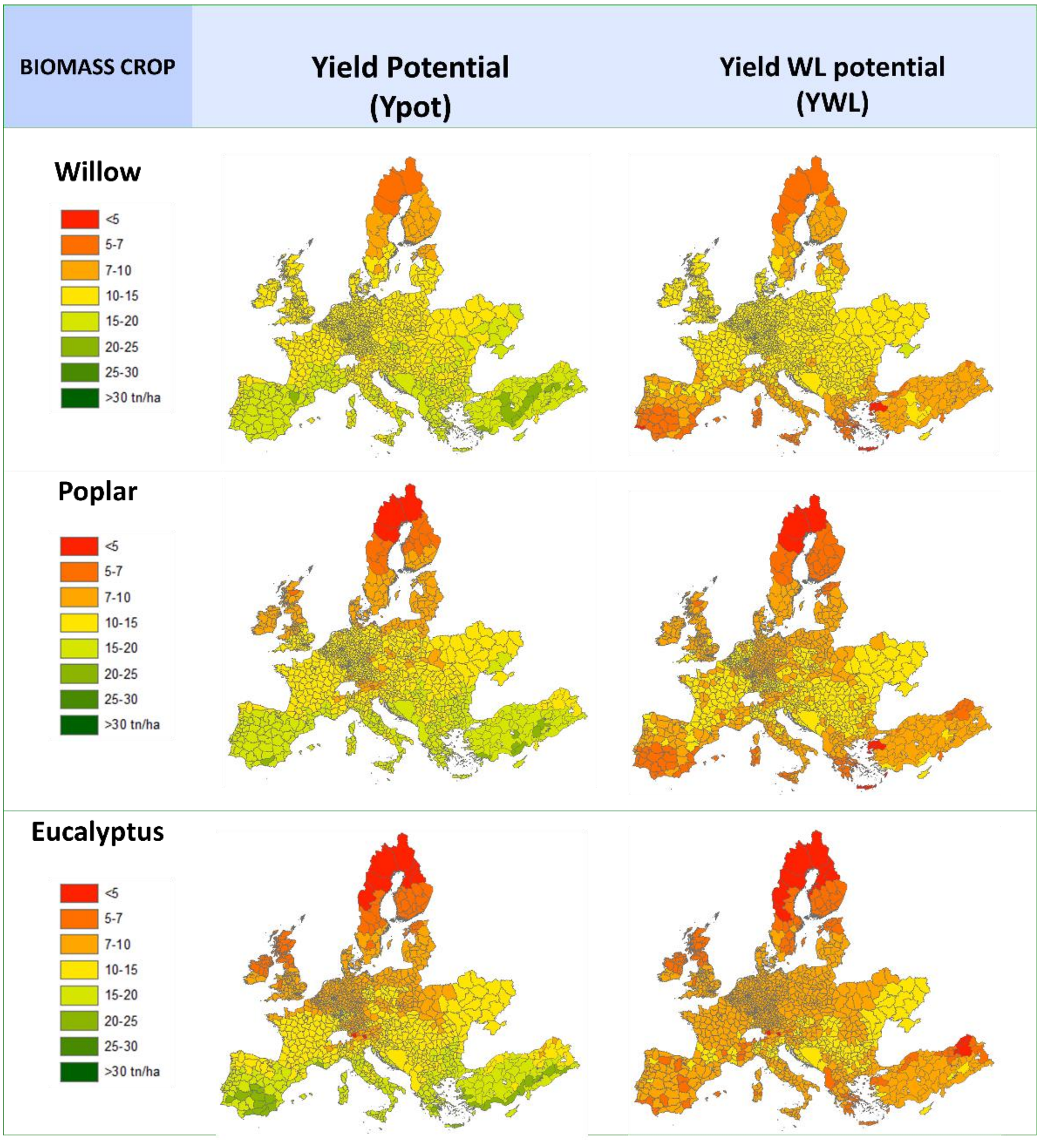




Annex A.7 Show the result from AquaCrop Model for lignocellulosic crops on Yield potentials and yields in water limitations.

BIOMASS CROP	Yield Potential	Yield WL potential
Miscanthus <5 5-7 7-10 10-15 15-20 20-25 25-30 >30 tn/ha		
Switchgrass <5 5-7 7-10 10-15 15-20 20-25 25-30 >30 tn/ha		
Giant Reed <5 5-7 7-10 10-15 15-20 20-25 25-30 >30 tn/ha		
Reed Canary Grass <5 5-7 7-10 10-15 15-20 20-25 25-30 >30 tn/ha		
Cardoon <5 5-7 7-10 10-15 15-20 20-25 25-30 >30 tn/ha		

Annex A.8 Show the result from Aquacrop model for lignocellulosic crops on Yield potentials and yields in water limitations. (SRC)



Annex A.9: Description of the scientific references collected for the experiment and review reporting data on location, NUTS classification code, environmental classification (Metzger et al., 2005), Production crop yield average and some information about the crop management to herbaceous crops: Miscanthus, Arundo donax, switchgrass, reed canary grass and cardoon

Species	Country/ Zone	Location	NUTS3	Enz/Ens	Crop age (year)	Rainfall (mm)	Yield (Mg ha^{-1} d.m.)	Crop management	References
Miscanthus	United Kingdom	Hampshire	UKJ36		7	709 AT/ 315 GS	14.5		Price et al., 2004
Miscanthus sp.	United Kingdom	Aberystwyth	UKL14		7	1100 AT	10.6		Zatta et al., 2014
	United Kingdom	Rothamsted	UKH23	ATC2	14	743 AT / 396 GS	12.8 ●	Fert. 0-120 kg N (N did not influence yield)/ harvest in winter	Christian et al., 2008
	Ireland southern	Cashel	IE024	ATN4	15	1004 AT	13.4	Harvest autumn	Clifton-Brown et al., 2007
	Ireland southern	Cashel	IE024	ATN4	15	1004 AT	9	Harvest spring	Clifton-Brown et al., 2007
	Denmark	Foulum	DK041		18	657 AT /309 GS (May to September)	13.1 (1997-2012)	Harvest late autumn	Larsen et al., 2014
	Germany	Ihinger hof (Iho)	DE244	ATC4	3	691 AT	29 to 30	First year Irrig. 300mm and fert. 50 kg N	Lewandowski and Heinz 2003
	Germany	Durmersheim	DE124	PAN1	3	780 AT	12 to 15	First year Irrig. 300mm and fert. 50 kg N	Lewandowski and Heinz 2003
	Germany	Klein Markow	DE80K	CON5	4 to 9	547 AT	7.5 to 12.6	N fertilizer/ plot size 45 m^2	Kahle et al., 2001
	Germany	Boitzenhagen	DE914	CON5	5 to 7	600 AT	8.8 to 13.5	N fertilizer/ plot size 300 m^2	Kahle et al., 2001
	Germany	Guntersleben	DE26C	CON4	6 to 8	603 AT	12.53	N fertilizer/ plot size 87 m^2	Kahle et al., 2001
	Serbia	Zemun	RS111		6	642 AT/ 333 GS	16.5	Irrig. only establishment (40 mm)/ fert	Stricevic et al., 2015
	Serbia	Zemun	RS111		6	642 AT/ 333 GS	21 to 23	Irrig. only establishment (40 mm)/fert. 50-100 kg N	Stricevic et al., 2015
	France	Grignon	FR103		21	557 AT	14.2	Irrig. and Fert. In the first year of the establishment	Dufosse et al., 2014
	France	Estrées-Mons	FR223	ATC5	5		13.94	Fert. rate did no effect	Lasorella et al., 2011
	Italy	Pisa	ITI17		12	857 AT	28.7	No Irrigation	Angelini et al., 2009
	Italy	Catania - sicily	ITG17		22	616±180 AT /290±86 GS	13.3	Irrig. (1st-3rd year) (80 mm, 215.5mm,76.5 mm respectly)	Alexopoulou et al., 2015
	Italy	Enna - sicily	ITG16	MDS	5	474 (March-January)	11 to 27	Irrig. 115-150mm (1st-3rd year, 25%)	Mantineo et al., 2009
	Italy	Enna - sicily	ITG16	MDS	5	474 (March-January)	18 to 30	Irrig. 438-450mm (1st-3rd year, 75%)	Mantineo et al., 2009
	Italy	Catania - Sicily	ITG17		3	81 to 241 GS (June - November)	14 to 17	Irrig. 15.8 mm (25%) irrigation/ fert. 0 kg N	Cosentino et al., 2007

Species	Country/ Zone	Location	NUTS3	Enz/Ens	Crop age (year)	Rainfall (mm)	Yield (Mg ha^{-1} d.m.)	Crop management	References
Miscanthus	Italy	Bologna	ITH55	MDN5	11		19.64	Irrig. During establishment year/Fert. rate did no effect/ plot size 90 m^2	Lasorella et al., 2011
Miscanthus sp.	Italy	Trisaia	ITF52		13		12.7	Irrig. During establishment year/Fert. rate did no effect/ plot size 50 m^2	Lasorella et al., 2011
	Greece	Thessaly	EL613	MDS1	5	194 - 336 GS (April-October)	13 to 35	Irrig. 400-600 mm (4-5cycle)	Danalatos et al., 2007
	Greece	Aliartos	EL641		6		14.41	Irrig. During establishment year/Fert. rate did no effect/ plot size 50 m^2	Lasorella et al., 2011
	EU and EE.UU						10 to 30		Zegada-Lizarazu et al., 2013
	Review						5 to 44		Lewandowski et al., 2003
	Austria						17 to 30		Nsanganwimana F. et al., 2014; Khanna et al., 2008
	United Kingdom						12 to 16		DEFRA, 2007
	Denmark						10 to 17*		Anderson et al., 2011
	Germany						10 to 30*		Anderson et al., 2011
	Portugal						26 to 39*		Anderson et al., 2011
	Spain						14		Anderson et al., 2011
	Netherlands						16 to 25*		Anderson et al., 2011
Arundo donax	Italy	Bologna	ITH55	MDN5	11	613±150 AT /409±87 GS	21.2	Irrig. only establishment /No fertilization was applied/ Harvest was carried out in wintertime	Alexopoulou et al., 2015
Giant Reed	Italy	Catania - Sicily	ITG17		18	616±180 AT /290±86 GS	15.7	Irrig. only establishment /No fertilization was applied/ Harvest was carried out in wintertime	Alexopoulou et al., 2015
	Italy	Pisa	ITI17		12		37.7	Pre-plant fertiliser (100 kg P2O5 ha^{-1}, 100 kg K2O ha^{-1} and 100 kg N ha^{-1} (urea)).	Angelini et al., 2009
	Italy	Naples	ITF33		9		13.9 to 16.2	Fert. 50-100 kg N; Harvest autumn-mid winter	Fagnano et al., 2015
	Italy	Ozzano	ITH55		16		16.8	Irrig. only establishment/ 0 kg N	Monti and Zegada-Lizarazu 2015

Species	*Country/ Zone*	*Location*	*NUTS3*	*Enz/Ens*	*Crop age (year)*	*Rainfall (mm)*	*Yield (Mg ha^{-1} d.m.)*	*Crop management*	*References*
Arundo donax	Italy	Ozzano	ITH55		16		17.7	Irrig. only establishment/ 50 kg N	Monti and Zegada-Lizarazu 2015
	Italy	Enna - Sicily	ITG16		5		30	Irrig. 115-150mm (1st-3rd year)	Mantineo et al., 2009
	Italy	Enna - Sicily	ITG16		5		35	Irrig. 438-450mm (1st-3rd year)	Mantineo et al.,2009
	Italy	Catania - Sicily	ITG47		3		12 to 24	Irrig and no irrig	Christou et al., 2003
	Greece	Thebes - Vagia	EL641		3		16 to 26	Irrig and no irrig	Christou et al., 2003
	Germany Northern	Braunschweig	DE911		3		15	Arundo D. under climatic conditions of N- W European countries	Bacher et al., 2001
	Germany Southern						8 to 26		Bacher et al., 2001; Oster and Schweiger 1992
	Italy		ITG16				20 to 53		Cosentino S.L. et al., 2008
	Germany						15 to 20		Elbersen W. et al., 2005
	Spain						8 to 37		Elbersen W. et al., 2005
	Greece Northern						5 to 17		Elbersen W. et al., 2005
	Greece Southern						7 to 31		Elbersen W. et al., 2005
	Greece						20 to 25		Elbersen W. et al., 2005
	Review						7 to 61		Zegada-Lizarazu et al., 2010
	Review						3 to 37		Lewandowski et al., 2003
Switchgrass	United Kingdom	Rothamsted	UKH23	ATC2	3		max 14.6 to 18.9		Elbersen W. et al., 2005
Panicum virgatum	United Kingdom	Rothamsted	UKH23	ATC2	5		10.2		Elbersen W. et al., 2005
	Netherlands	Wageningen	NL221	ATC2	3		19.6		Elbersen W. et al., 2005
	Netherlands	NO polder	NL230	ATN4	3		max 10.7		Elbersen W. et al., 2005
	Germany	Braunschweig	DE911		3		max 8 to 14.5		Elbersen W. et al., 2005
	Italy	Trisaia	ITF52		3		max 19 to 26		Elbersen W. et al., 2005
	Italy	Bologna	ITH55		11	613±150 AT /409±87 GS	13.6	Irrig. only establishment	Alexopoulou et al., 2015
	Italy	Trisaia	ITF52		5	400	11.1	Irrig. 240mm	Alexopoulou et al., 2008
	Italy	Pisa	ITI17		3	627 to 936 AT/ 191 to 536 GS	25	Alamo/ fert. 50-100 kg N/ irrig. 0-75% ET0 (no effect)	Lasorella M.V. 2014

Species	Country/ Zone	Location	NUTS3	Enz/Ens	Crop age (year)	Rainfall (mm)	Yield (Mg ha^{-1} d.m.)	Crop management	References
Switchgrass	Italy	Pisa	ITI17		3	627 to 936 AT/ 191 to 536 GS	19	Blackwell / fert. 50-100 kg N/ irrig. 0-75% ET0 (no effect)	Lasorella M.V. 2014
	Greece	Aliartos	EL641		5	400	15.2	Irrig. 345-430 mm	Alexopoulou et al., 2008
	Greece	Aliartos	EL641		3		22		Elbersen W. et al., 2005
	EU and EE.UU						9 to 25		Zegada-Lizarazu et al., 2013
	EU (Review)						10 to 25		Zegada-Lizarazu et al., 2010
	EU (Review)						5 to 23		Lewandowski et al., 2003
	Europe	Higher latitude					8 to 14		Elbersen W. et al., 2013
	Europe	Lower latitude					up to 20		Elbersen W. et al.,2013
RCG	Finland	Jokioinen	FI1C2		4		10.2		Sahramaa et al., 2003
Phalaris arundinacea	Finland	Jokioinen	FI1C2				13		Kandel et al., 2016
	United Kingdom	Rothamsted	UKH23	ATC2			max 16		Elbersen W. et al., 2005
	United Kingdom	Dundee	UKM21				17 to 19		Elbersen W. et al., 2005
	Netherlands	Groningen	NL113				2 to 8		Elbersen W. et al., 2005
	EU and EE.UU.						3 to 14		Zegada-Lizarazu et al., 2013
	Review						15		EEA, 2007; Lewandowski et al., 2003
	Review						7 to 13		Bassam, 2010
	Sweden						6 to 11		Elbersen W. et al., 2005
	Denmark						9		Elbersen W. et al., 2005
	Ireland						8		Elbersen W. et al., 2005
	Germany						7		Elbersen W. et al., 2005
	Finland						7.5 to 9	marginal soil	Lord R.A., 2015
	Lithuania						6.5 to 7.5	marginal soil	Lord R.A., 2015
Cardoon	Spain	Madrid	ES300		3		14		Fernandez et. Al., 2006
Cynara cardunculus	Italy	Enna - Sicily	ITG16		3	460-640 (August-July)	7 to 23.5	Irrig. 115-150mm (1st-3rd year, 25%)	Mantineo et al., 2009
	Italy	Enna - Sicily	ITG16		3	460-640 (August-July)	7.9 to 26.4	Irrig. 438-450mm (1st-3rd year, 75%)	Mantineo et al., 2009

Species	*Country/ Zone*	*Location*	*NUTS3*	*Enz/Ens*	*Crop age (year)*	*Rainfall (mm)*	*Yield (Mg ha^{-1} d.m.)*	*Crop management*	*References*
Cardoon	Italy	Pisa	ITI17		11	860 (annual)	13 to 14		Angelini et al., 2009
	Spain	Madrid	ES300		3	280-529 (August-July next year)	6.5 to 16.3		Fernandez J. 2009.
	Greece	Tebas			3	324-490 (August-July next year)	27.9 to 28.6		Fernandez J. 2009.
	Italy	Forly			3	752-837 (August-July next year)	17.5 to 19.7		Fernandez J. 2009.
	Italy	Policoro			3	316-722 (August-July next year)	7.5 to 12.9		Fernandez J. 2009.
	Italy	Sicily			3	387-654 (August-July next year)	13.3 to 15.9		Fernandez J. 2009.
	Mediterranean area						18	Scen. High: high input, any constraints	Optima data expert
	Mediterranean area						14	scen. Standard	Optima data expert
	Mediterranean area						9.8	Scen. marginal 1	Optima data expert
	Mediterranean area						5.6	Scen. marginal 2	Optima data expert

*Different period of harvest; **excluding the establishment year; GS: growing season; AT: mean annual total rainfall (mean annual precipitation); ●: Average all year without excluding establishment date; Enz/Ens: Environmental zone and sub-zone; NR: no reference

Annex A.10: Description of the scientific references collected for the experiment and review reporting data on location, production crop yield average and some information about the crop management to SRC crops: willow, poplar and eucalyptus.

Crop	*Species*	*Country/ Zone*	*Location*	*NUTS3*	*Crop age (year)/cycle*	*Annual Yield (t ha^{-1} d.m.)*	*Crop management*	*References*
Willow	*Salix viminalis*	Sweden				36	on irrigated and fertilised small plots in Southern Sweden	Ceulemans et al., 1996
Salix sp.	*Salix sp.*	Sweden				10 to 12		Ceulemans et al., 1996
	Salix sp. (various clones)					15 to 22		Sugiura, A. 2009
	Salix viminalis				2nd	11.7 to 19.6		Sugiura, A. 2009
	Salix sp.	USA	Vermont			9.2		Amichev et al., 2011
	Salix sp.	USA	New York			12.8		Amichev et al., 2011
	Salix sp.	USA				7.4 to 20.7		Amichev et al., 2011
	Salix sp.	Canada				12		Amichev et al., 2011
	Salix dasyclados	Canada				28. 5		Ceulemans et al., 1996
	Salix sp.	Review			22 to 30	10 to 30	Harvested on 3–4 years rotation (winter)	Zegada-Lizarazu et al., 2010
	Salix sp.	Review				5 to 25		Dallemand et al., 2008
	Salix aquatica	Ireland	Northern			12 to 15	on marginal agricultural land	Ceulemans et al., 1996
	Salix sp.	Ireland				18		Ceulemans et al., 1996
	Salix aquatica	Finland				6.5 to 7.6	on abandoned farmland	Ceulemans et al., 1996
	Salix sp.	UK	Rothamsted - Harpenden		2nd rotation	14.1	Two year rotation	Cuniff J. et al., 2015
	Salix sp.	UK	Aberystwyth (wales)		2nd rotation	11.5	Two year rotation	Cuniff J. et al., 2015
	Salix sp.	Italy	Northern			3 to 26		Cosentino et al., 2008; Facciotto et al., 2005
	Salix sp.	Italy	Central			1 to 19		Cosentino et al., 2008; Facciotto et al., 2005
	Salix sp.	Italy	Central			13 yearly average		Cosentino et al., 2008; Di Candilo et al., 2005
Poplar	*Populus trichocarpa*	USA				27.5	Results of the improved hybrids grown	Ceulemans et al., 1996
Populus sp.	*Populus sp.*	Review				7 to 28		Zegada-Lizarazu et al., 2010
	Populus sp.	Review				12		Fazio and Barbanti 2014
	Populus sp. (hydrid poplar)					11 to 28		Sugiura, A. 2009

Crop	Species	Country/ Zone	Location	NUTS3	Crop age (year)/cycle	Annual Yield (t ha^{-1} d.m.)	Crop management	References
Poplar	*poplar hybrids (i.e. P. tremula × P. tremuloides)*	Germany				10 t of dry matter per hectare annually	depend also of the density	FAO, 2012 International Poplar Commission
	poplar hybrids	Germany				20 and higher	high precipitation or groundwater impact also guaranteeing a continuous growth in dry periods	FAO, 2012 International Poplar Commission
	poplar hybrids	Germany				6 or less	poor water supply the	FAO, 2012 International Poplar Commission
	Populus sp.	Italy				25	The clones/provenances used in short-rotation-coppice trials have shown yields of up to 25 tons (oven dry) per ha and year	FAO, 2012 International Poplar Commission
	Populus sp.	Italy				6 to 12 ha/year	where fertilization and irrigation are rarely applied by farmers	FAO, 2012 International Poplar Commission
	Populus sp.	Italy	Northern			3 to 25		Cosentino et al., 2008; Facciotto et al., 2005
	Populus sp.	Italy	Central			1 to 25		Cosentino et al., 2008; Facciotto et al., 2005
	Populus sp.	Italy	Central			17 to 22	17, low input and 22 high input	Cosentino et al., 2008; Bonari et al., 2005
	Populus sp.	Italy	Central			14		Cosentino et al., 2008; Di Candilo et al., 2005
Eucalyptus *Eucalyptus sp.*	*Eucalyptus globulus*					13.23		Sugiura, A. 2009
	Eucalyptus botryoides					22 to 27		Sugiura, A. 2009
	Eucalyptus ovata					15.17		Sugiura, A. 2009
	Eucalyptus grandis					12.03		Sugiura, A. 2009
	Eucalyptus sp.	Review			20 to 25	10.4 to 25.5	short rotations harvested every 2–3 years (winter)	Zegada-Lizarazu et al., 2010
	Eucalyptus sp.	Greece				25.5		Ceulemans et al., 1996

Annex A.11: Description of the scientific references collected for the experiment and review reporting data of **Biomass characterization.** Detail data ref. Elbersen et al. 2016. Annex2 http://www.s2biom.eu/images/Publications/D2.4_Database_for_standardized_biomass_characterisation_Final_01112016c.pdf

General group	*Unit*		*Annual and perennial biomass crops*							*SRC*			
			Reed canary grass	*Switchgrass*	*Miscanthus*	*Giant Reed*	*Cardoon*	*Fibre sorghum*	*References*	*Willow*	*Poplar*	*Eucalyptus*	*References*
			Phalaris arundinacea	*Panicum virgatum L.*	*Miscanthus spp.*	*Arundo donax L.*	*Cynara cardunculus L.*	*Sorghum bicolour L.*		*Salix humilis Marsh.*	*Populus spp.*	*Eucalyptus Spp.*	
Moisture content	**w-% ar**	Mean	20	11.58	39.76	39.06	9.3	7.04	Phyllis2	40	40	40	S2BIOM Biomass properties
		Minimum		8.16	24	36.1	6.8			30	30	35	
		Maximum		15	46	42.01	11			50	50	50	
Bulk density, BD	**kg/m³ ar**	Mean					220		Phyllis2	330	340	340	S2BIOM Biomass properties
		Minimum								300	320	320	
		Maximum								390	400	400	
Net calorific value, dry	**MJ/kg**	Mean	16.5	16.64	17.98	17.38	15.57	15.85	*Phyllis2*	18.4	18.4	18.1	S2BIOM Biomass properties
		Minimum	16.5	15.95	17.14	17.17	15.08	15.47		17.7	17.3	17.6	
		Maximum	17	17.66	20.39	17.58	16.05	16.24		19	18.8	18.4	
Net calorific value as received (ar)	**MJ/kg**	Mean	12.7	14.86	10.16	9.63	14.18	16.9	Phyllis2; S2BIOM Biomass properties	10.1	10.1	9.9	S2BIOM Biomass properties
		Minimum	12.7	13.9	7.7	9.17		16.43		7.6	7.4	7.6	
		Maximum	13.1		16.34	10.09		17.65		11.5	12.4	11.1	
Gross Calorific value	**MJ/kg**	Mean	17.7	19.04	19.98	18	19.08	19.4	*Phyllis2; S2BIOM Biomass properties*	19.9	19.8	19.5	S2BIOM Biomass properties
		Minimum	17.7	18.29	19.61	17.81	18.11	18.98		19.2	19.5	19.3	
		Maximum	18	20.05	20.48	18.2	20.26	19.85		20.4	20.1	21.2	
Ash content	**w-% dry**	Typical	6.5	6.33	3.8		8.38	6.76	Phyllis2; S2BIOM Biomass properties; Lewandowski I. et al., 2003.	2	2	2	S2BIOM Biomass properties
		Minimum	1	4.5	1.6	4.8	5.1	5.42		1.1	0.2	0.2	
		Maximum	8	10.5	4	7.8	13.9	10.18		4	3.4	6.1	

General group		Unit	Reed Canary grass	Switchgrass	Miscanthus	Giant reed	Cardoon	Fibre Sorghum	References	Willow	Poplar	Eucalyptus	References
Ash melting behavior (DT)	°C	Mean	1227		851			953	*Phyllis2*	1363	1320	1330	S2BIOM Biomass properties
		Minimum	990		650			850		1164	1320	1320	
		Maximum	1540		980			1120		1467	1370	1370	
Content of lignin	**w-% dry**	Mean	4.64	6.77	21.3	17.97		8.75	Phyllis2	26.3	22.9	23.2	S2BIOM Biomass properties
		Minimum	4	5.3	21	16.8		6			15.5	9	
		Maximum	5.3	12.1	21.6	19.4		16			31.9	37	
Content of cellulose	**w-% dry**	Mean	32.2	36.85	44.55	32.91		39.89	*Phyllis2*	44.4	44.4	43	S2BIOM Biomass properties
		Minimum	26	32	44.1	26.6		29		35.2	35.2	8.8	
		Maximum	38.5	38.5	45	43.8		47.2		50.8	50.8	57.5	
Content of hemicellulose	**w-% dry**	Mean	24.6	32.13	23.9	27.16		25.15	Phyllis2	25.3	25.3	25.3	S2BIOM Biomass properties
		Minimum	16.5	30.8	17.8	25.74		18		12.7	12.7	8.4	
		Maximum	28	33.6	30	28.33		27		39.8	39.8	43.5	
N	**w-% dry**	Mean	1.3	0.63	0.51	0.47	0.99	0.92	*Phyllis2; S2BIOM Biomass properties; Lewandowski I. et al. 2003.*	0.5	0.4	0.3	S2BIOM Biomass properties
		Minimum	0.4	0.4	0.19	0.31	0.59	0.42		0.2	0.1	0.03	
		Maximum	2	1.3	0.67	0.62	1.31	1.45		1.12	0.6	1.7	
Cl	**w-% dry**	Mean	0.9						S2BIOM Biomass properties; Lewandowski I. et al. 2003.	0.02	0.03	0.02	S2BIOM Biomass properties
		Minimum	0.02		0.1					0.02	0.08	0.018	
		Maximum	0.6		0.5					0.04	0.05	0.04	
S	**w-% dry**	Mean	0.13	0.14	0.06	0.11	0.16	0.08	*Phyllis2; S2BIOM Biomass properties; Lewandowski I. et al. 2003.*	0.05	0.03	0.05	S2BIOM Biomass properties
		Minimum	0.04	0.1	0.04	0.1	0.12	0.05		0.02	0.02	0	
		Maximum	0.17	0.21	0.19	0.12	0.22	0.09		0.12	0.1	0.4	
F	**w-% dry**	Mean								0.003		0.01	S2BIOM Biomass properties
		Minimum											
		Maximum											

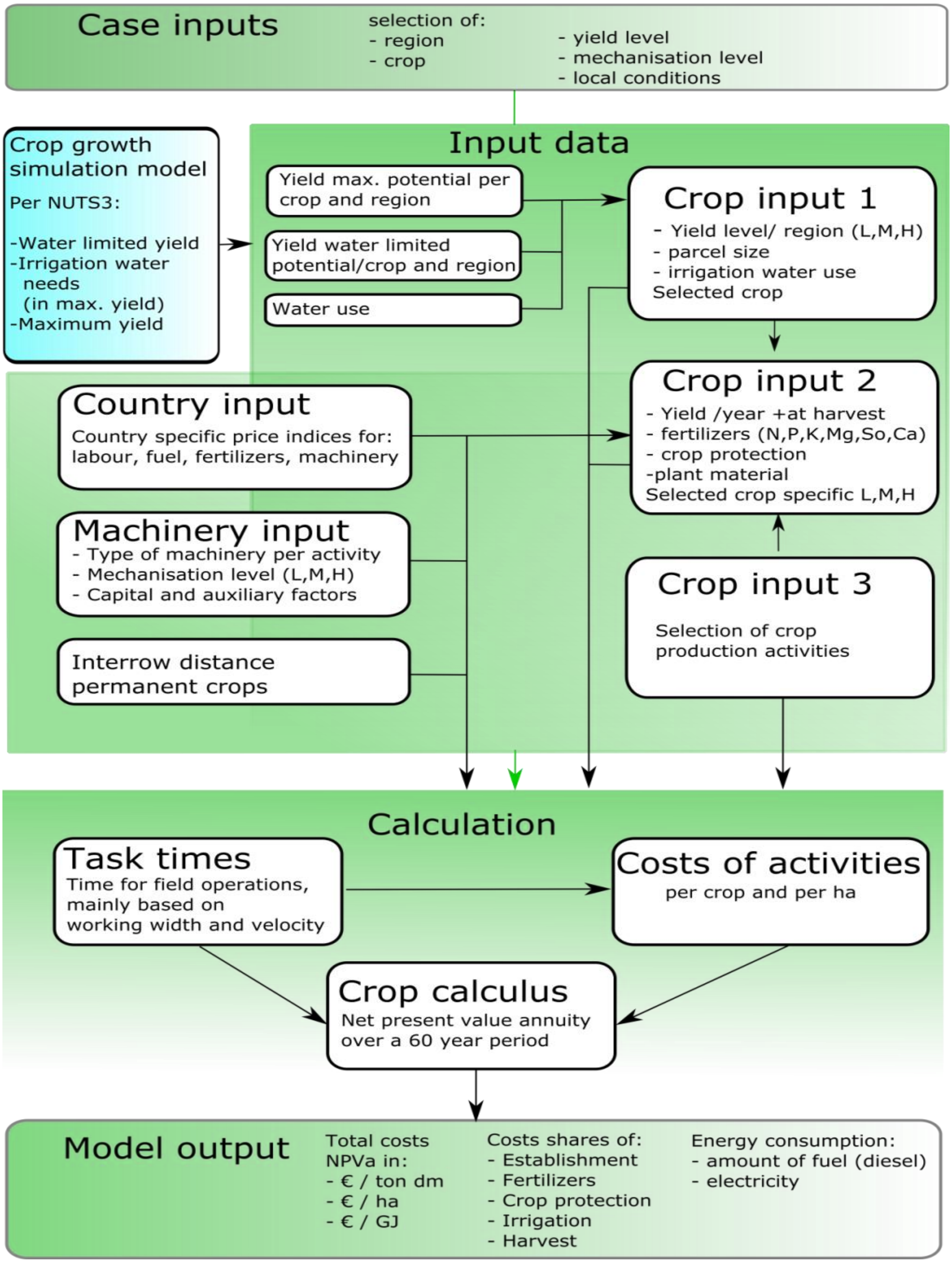
General group	Unit		Reed Canary grass	Switchgrass	Miscanthus	Giant reed	Cardoon	Fibre Sorghum	References	Willow	Poplar	Eucalyptus	References
Na_2O (ash)	**w-% dry**	Mean	0.31	0.26	0.2	0.4	7	0.49	*Phyllis2*	2.01	0.25	4.98	Phyllis2
		Minimum	0.05	0.1	0.07	0.3	6.3	0.17		0.77	0.1		
		Maximum	0.9	0.5	0.48	0.49	7.7	1.31		3.05	0.4		
K_2O (ash)	**w-% dry**	Mean	3.63	12.72	15.32	29.5	10.55	21.02	Phyllis2	14.38	17.55	7.2	Phyllis2
		Minimum	2	8.1	2.4	29	9.1	8.19		10.1	10.72		
		Maximum	7.1	21.3	34.7	30	12	33.6		19.9	24.37		
Fe_2O_3 (ash)	**w-% dry**	Mean	0.68	0.39	0.33	0.86	0.92	0.89	*Phyllis2*	0.61	0.57		Phyllis2
		Minimum	0.2	0.35	0.08		0.87	0.39		0.2			
		Maximum	1.13	0.45	0.87		0.96	1.82		1.4			
CaO (ash)	**w-% dry**	Mean	4.78	9.06	5.63	2.89	24.5	9.26	Phyllis2	37.01	38.26	26.52	Phyllis2
		Minimum	2	4.8	3	2.78	20	8		25.1	29.24		
		Maximum	9	12.1	10.1	3	29	11.8		45.62	47.28		
MgO (ash)	**w-% dry**	Mean	1.48	4.34	2.83	5.64	3.35	3.36	*Phyllis2*	3.41		7.25	Phyllis2
		Minimum	0.6	2.6	0.88	3.07	3.3	2.65		1.16			
		Maximum	3.2	5.8	4.86	8.2	3.4	4		7.67	11.58		

References

- Lewandowski I. et al. 2003. The development and current status of perennial rhizomatous grasses as energy crops in the US and Europe. Biomass and bioenergy 25. 335-361.
- El Bassam N., 2010. Handbook of Bioenergy Crops “A Complete Reference to species, Development and Applications”. ISBN 978-1-84407-854-7
- Rettenmaier N., Gärtner S., Heiko Keller H., Müller-Lindenlauf M., Reinhardt G., Schmidt T., 2015. Optima Project WP 7 Integrated assessment of sustainability, Deliverable D 7.10: Final report on Tasks 7.1, 7.2 and 7.4, Part B: Report on Life cycle assessment (Task 7.2).
- Nsanganwimana Florien, Pourrut Bertrand, Mench Michel, Douay Francis, 2014. Suitability of Miscanthus species for managing inorganic and organic contaminated land and restoring ecosystem services. A review. Journal of Environmental Management 143 (2014) 123-134.
- Angelini L. G., Ceccarini L., Nassi o Di Nasso N., Bonari E. 2009. Long-term evaluation of biomass production and quality of two cardoon (Cynara cardunculus L.) cultivars for energy use. Biomass and bioenergy 33 (2009).
- Cosentino S.L. et al 2008. Agronomic, Energetic and Environmental Aspects of Biomass Energy Crops Suitable for Italian Environments. *Ital. J. Agron. / Riv. Agron., 2008, 2:81-95.*
- Miles, T. R., T. R. Miles, Jr, L. Baxter, R. W. Bryers, B. M. Jenkins and L. Oden: Alkali deposits found in biomass power plants. A preliminary investigation of their extend and nature, NREL/TP-433-8142, 82 p. (1995).
- Murphy et al. 2014. Energy requirements and environmental impacts associated with the production of short rotation willow (Salix sp.) chip in Ireland. GCB Bioenergy (2014) 6, 727–739,
- Wickham, J., Rice, B., Finnan, J. and McConnon, R. 2010. A review of past and current research on short rotation coppice in Ireland and abroad. COFORD, Dublin.
- Rodríguez Pleguezuel et al. 2015. Bioenergy farming using woody crops. A reviewAgron. Sustain. Dev. (2015) 35:95–119.
- Navarro et al. 2015. Feasibility of SRC Species for Growing in Mediterranean Conditions. Bioenerg. Res.
- Phyllis2, database for biomass and waste, https://www.ecn.nl/phyllis2,Energy research Centre of the Netherlands.

Annex A.12 Overview of ABC cost calculation model for dedicated biomass crops.

Source: Schrijver et al., 2016 and Dees et al., 2017a



Annex 13: Results in UD01 (Strict suitability) for low quality land in 2030 projection. Include the three crops selection. Total biomass production according the land available. Cost production average in euro/ton dm.

NUTS code		***Land (1000 ha)***			***Crop selection & yield amount (Kton)***								***Yield (kton)***	***Cost (EUR/ton)***
NUTS0	***NUTS3***	***Total polygon area***	***Utiliased Agricultural Area (UAA 2012)***	***Land availability (Low Q. 2030)***	***misc***	***switch***	***Giant***	***rcg***	***card***	***will***	***popl***	***eucal***	***∑yield pot. in low-quality land***	***Production Cost avg***
IT	ITC11	683.0	528.5	13.6	-	18.2	-	15.9	-	51.1	-	-	85.2	66.2
IT	ITC12	208.3	161.2	4.0	-	5.3	-	4.6	-	14.7	-	-	24.6	66.8
IT	ITC13	91.4	70.8	1.7	3.5	2.6	-	-	-	-	-	5.4	11.5	64.2
IT	ITC14	226.2	168.4	0.9	-	1.0	-	0.9	-	2.9	-	-	4.8	73.4
IT	ITC15	134.1	102.5	2.9	-	-	-	-	-	-	-	-		
IT	ITC16	689.9	533.6	13.3	-	19.4	-	17.0	-	54.0	-	-	90.4	62.6
IT	ITC17	151.1	117.0	3.4	8.0	6.1	-	-	-	-	-	12.3	26.4	58.4
IT	ITC18	356.2	274.8	7.5	18.1	27.7	19.9	-	-	-	-	-	65.7	66.4
IT	ITC20	326.0	154.6	0.2	0.3	0.2	-	0.4	-	-	-	-	0.9	81.4
IT	ITC31	115.5	23.7	0.3	1.6	0.6	0.9	-	-	-	-	-	3.1	122.9
IT	ITC32	154.7	31.9	0.5	2.1	0.8	1.4	-	-	-	-	-	4.3	129.1
IT	ITC33	183.4	37.8	0.4	0.8	-	0.9	-	-	-	-	1.3	3.1	106.1
IT	ITC34	88.2	18.2	0.2	-	-	-	-	-	-	-	-		
IT	ITC41	119.9	41.1	1.4	3.2	2.4	-	-	-	-	-	4.8	10.4	66.0
IT	ITC42	127.8	44.2	1.2	2.5	1.9	-	-	-	4.3	-	-	8.7	67.7
IT	ITC43	81.5	27.7	0.4	1.0	0.7	-	-	-	-	-	1.5	3.3	64.6
IT	ITC44	319.8	118.8	1.1	-	1.0	-	0.9	-	3.1	-	-	5.1	87.6
IT	ITC46	274.8	101.3	3.3	7.2	5.4	-	-	-	-	-	11.2	23.8	65.3
IT	ITC47	478.8	169.4	6.5	10.7	15.9	11.6	-	-	-	-	-	38.2	89.0
IT	ITC48	297.1	110.9	3.9	18.6	6.9	9.8	-	-	-	-	-	35.2	71.5
IT	ITC49	78.4	29.2	1.3	5.8	2.2	3.2	-	-	-	-	-	11.2	72.0
IT	ITC4A	177.2	65.9	2.8	12.6	4.9	7.1	-	-	-	-	-	24.6	71.8
IT	ITC4B	234.2	87.3	3.7	16.9	6.7	9.6	-	-	-	-	-	33.2	71.4
IT	ITC4C	157.7	58.7	2.4	11.2	4.4	6.3	-	-	-	-	-	21.8	72.0

Annex A.14 Overview of yield-cost crop combinations for the three management levels assumed at national level

Table A.14.1 Average yield (Mg ha^{-1} d.m./ha/year, from AquaCrop simulation) and road side cost (€/ton d.m.) low management level (L1) for EU28 and Non-EU. Note that the results in the tables do not take account of the soil and climatic limiting factors (land suitability).

	Miscanthus		Switchgrass		Giant reed		RCG		Cardoon		Willow		Poplar		Eucalyptus	
Country	**Yield**	**cost**	**Yield**	**cost**	**Yield**	**cost**	**Yield**	**cost**	**Yield**	**cost**	**Yield**	**cost**	**Yield**	**cost**	**Yield**	**Cost**
AL	6.9	38	5.1	27	7.8	46	4.4	30	4.8	40	6.7	35	6.2	37	5.4	41
AT	6.7	95	5.0	106	7.0	123	4.2	117	4.4	164	6.7	75	5.6	89	4.9	103
BA	10.0	28	7.4	22	10.1	39	5.6	25	6.3	34	8.4	29	8.1	30	7.0	32
BE	6.6	106	5.0	119	6.8	131	4.2	132	4.3	174	6.4	101	5.6	115	4.7	133
BG	9.9	53	7.4	54	10.8	62	5.1	75	6.6	72	7.6	58	7.7	56	7.5	54
CY	11.4	74	8.9	83	15.0	76	5.3	123	9.3	95	8.1	86	8.2	84	9.5	71
CZ	6.5	56	4.9	51	7.1	69	4.3	55	4.5	75	6.8	48	5.5	58	5.0	62
DE	6.5	127	4.8	148	6.9	153	4.2	166	4.3	205	6.7	103	5.5	120	4.9	131
DK	5.7	180	4.3	213	6.0	215	3.6	243	3.8	285	6.0	153	4.7	191	4.2	208
EE	4.7	59	3.5	44	4.9	75	3.0	50	3.2	73	4.8	54	4.0	63	3.5	71
EL	6.2	126	4.8	140	8.4	115	3.2	206	5.1	160	4.9	130	5.0	123	5.7	107
ES	8.0	70	6.1	72	9.4	85	4.2	96	5.8	102	6.3	74	6.3	72	6.4	67
FI	4.0	159	3.0	174	4.1	203	2.6	195	2.6	262	4.3	125	3.4	150	2.9	173
FR	8.0	81	6.0	88	8.5	105	4.8	106	5.2	133	7.2	75	6.6	80	5.9	85
HR	9.2	34	6.9	27	10.1	45	4.8	34	6.2	44	7.2	37	7.3	36	7.0	36
HU	8.9	50	6.6	48	9.7	64	4.9	60	6.0	67	7.4	50	7.2	50	6.8	50
IE	5.0	150	3.8	168	5.0	188	3.5	176	3.2	237	5.3	129	4.6	146	3.5	183
IT	8.5	111	6.5	129	10.0	129	4.3	172	6.1	165	6.6	119	6.6	117	6.9	108
KS	7.8	34	5.8	25	8.4	43	5.1	26	5.2	38	8.4	29	6.3	37	5.8	38
LT	5.5	60	4.1	50	5.9	77	3.4	62	3.7	76	5.7	51	4.5	61	4.1	62
LU	6.3	103	4.7	112	7.0	126	4.2	122	4.3	160	6.7	88	5.6	103	4.8	113
LV	5.3	50	3.9	35	5.5	66	3.2	40	3.5	60	5.3	47	4.3	56	3.9	60
MD	8.8	30	6.6	22	9.6	39	4.8	26	6.0	33	7.5	31	7.0	33	6.7	32
ME	9.0	31	6.7	23	9.8	40	5.9	24	6.1	35	8.9	27	7.8	31	6.9	33
MK	8.5	31	6.3	22	9.4	38	4.8	25	5.8	32	7.2	32	7.1	32	6.6	33
MT	10.2	178	7.9	224	13.3	178	4.7	380	8.2	262	7.1	187	7.3	180	8.5	151
NL	6.2	303	4.6	384	6.5	326	4.0	438	4.1	486	6.3	263	5.3	307	4.6	352
PL	6.2	62	4.6	56	6.8	72	4.0	63	4.3	78	6.5	54	5.2	65	4.8	69
PT	7.9	60	6.0	58	9.9	71	4.1	79	6.1	80	6.1	62	6.3	59	6.9	50
RO	8.4	51	6.3	48	9.1	63	4.7	59	5.7	65	7.3	47	6.8	49	6.3	49
RS	9.1	30	6.8	22	9.8	39	4.9	27	6.1	35	7.5	32	7.3	32	6.8	33
SE	4.4	150	3.3	163	4.6	193	2.9	177	2.9	247	4.8	122	3.8	151	3.2	178
SI	7.7	96	5.7	111	8.1	115	4.7	144	5.1	162	7.2	81	6.4	88	5.7	96
SK	7.6	43	5.7	36	8.3	55	4.7	39	5.2	55	7.3	39	6.3	45	5.8	48
TR	7.9	41	6.0	33	9.1	51	4.4	43	5.6	50	6.7	40	6.4	42	6.2	40
UA	7.6	35	5.6	24	8.1	44	4.5	27	5.1	37	7.1	33	6.2	37	5.7	39
UK	5.7	112	4.2	121	5.9	141	3.9	135	3.7	179	6.0	95	5.0	112	4.1	132

Table A.14.2 Average yield (Mg ha^{-1} d.m./ha/year, from AquaCrop simulation) and road side cost (€/ton d.m.) medium management level (L2) for EU28 and Non-EU. Note that the results in the tables do not take account of the soil and climatic limiting factors (land suitability).

	Miscanthus		Switchgrass		Giant reed		RCG		Cardoon		Willow		Poplar		Eucalyptus	
Country	**Yield**	**cost**	**Yield**	**cost**	**Yield**	**cost**	**Yield**	**cost**	**Yield**	**cost**	**Yield**	**cost**	**Yield**	**cost**	**Yield**	**Cost**
AL	8.6	35	6.4	24	9.7	41	5.5	26	6.0	35	8.4	32	7.8	34	6.7	38
AT	12.0	58	8.9	64	12.4	77	7.4	70	7.8	100	11.8	46	9.9	55	8.6	62
BA	15.5	22	11.5	18	15.5	31	8.6	20	9.6	27	12.9	22	12.5	23	10.8	24
BE	12.0	63	8.9	70	12.2	80	7.6	76	7.7	103	11.6	60	10.0	68	8.5	78
BG	14.1	43	10.6	45	15.4	52	7.2	61	9.4	59	10.9	46	11.0	45	10.7	43
CY	17.7	53	13.9	60	23.1	58	8.2	84	14.3	69	12.5	60	12.7	59	14.7	49
CZ	11.8	36	8.8	33	12.6	46	7.7	34	7.9	49	12.1	31	9.8	37	8.8	39
DE	11.6	81	8.7	95	12.0	104	7.3	108	7.6	134	11.6	66	9.6	76	8.4	81
DK	10.2	113	7.7	133	10.7	140	6.4	152	6.8	179	10.8	93	8.5	115	7.5	122
EE	8.5	37	6.4	28	8.6	49	5.3	33	5.5	48	8.3	35	6.9	41	6.0	46
EL	7.8	107	6.0	116	10.6	97	4.0	168	6.4	132	6.1	111	6.3	105	7.1	90
ES	10.1	61	7.7	62	12.0	74	5.4	81	7.4	87	8.1	64	8.1	62	8.1	57
FI	7.2	100	5.4	111	7.4	131	4.6	123	4.7	164	7.6	78	6.1	93	5.2	105
FR	12.7	60	9.5	65	13.0	79	7.4	80	8.1	99	11.2	55	10.2	58	9.1	60
HR	13.9	26	10.5	21	15.3	35	7.3	25	9.4	34	11.0	28	11.1	28	10.7	27
HU	13.4	40	10.0	40	14.4	53	7.3	48	8.9	55	11.0	39	10.7	39	10.0	38
IE	9.0	95	6.8	106	9.0	123	6.3	111	5.8	149	9.6	79	8.3	89	6.3	109
IT	11.8	89	9.0	104	13.7	106	6.0	134	8.4	131	9.1	94	9.1	92	9.4	83
KS	12.1	26	9.0	20	13.0	34	7.8	20	8.1	30	12.9	22	9.7	28	9.0	28
LT	10.0	43	7.5	39	10.5	57	6.1	47	6.7	56	10.2	35	8.0	42	7.4	41
LU	11.3	66	8.5	72	12.5	83	7.6	79	7.8	104	12.0	55	10.0	64	8.7	68
LV	9.5	33	7.1	24	9.9	44	5.8	26	6.3	40	9.5	30	7.7	36	6.9	38
MD	13.9	23	10.4	18	14.6	31	7.3	20	9.1	27	11.4	24	10.6	26	10.2	25
ME	14.0	24	10.5	18	15.2	32	9.1	19	9.4	28	13.8	21	12.0	24	10.6	25
MK	10.6	28	7.9	20	11.8	35	6.0	22	7.2	29	9.0	30	8.8	30	8.2	30
MT	15.9	125	12.3	159	20.6	131	7.2	259	12.7	187	11.0	130	11.3	124	13.1	103
NL	11.1	178	8.3	226	11.7	196	7.3	256	7.4	285	11.4	153	9.6	178	8.2	201
PL	11.2	40	8.4	36	12.1	48	7.2	40	7.6	50	11.5	34	9.3	41	8.5	43
PT	9.8	54	7.5	52	12.4	64	5.1	70	7.7	71	7.6	56	7.9	53	8.6	45
RO	13.8	39	10.3	38	14.8	51	7.8	47	9.2	52	12.0	35	11.1	36	10.3	35
RS	13.7	24	10.1	19	14.7	32	7.4	21	9.1	28	11.2	25	11.0	25	10.2	26
SE	7.9	93	6.0	101	8.2	122	5.2	109	5.3	152	8.6	75	6.8	92	5.8	106
SI	13.8	62	10.3	71	14.2	75	8.1	93	8.8	104	12.6	53	11.1	57	9.9	60
SK	12.8	30	9.5	25	13.5	40	7.6	27	8.4	40	12.0	28	10.3	32	9.4	33
TR	9.9	38	7.5	30	11.4	46	5.4	38	7.0	45	8.4	37	8.0	38	7.8	37
UA	13.7	24	10.2	18	14.5	31	8.1	19	9.1	27	12.7	22	11.1	25	10.2	25
UK	10.2	72	7.6	78	10.5	92	6.9	88	6.6	115	10.7	60	8.9	70	7.4	80

Table A.14.3 Average yield (Mg ha^{-1} d.m./ha/year from Aquacrop simulation) and road side cost (€/ton d.m.) high management level (L3) for EU28 and Non-EU. Note that the results in the tables do not take account of the soil and climatic limiting factors (land suitability).

	Miscanthus		Switchgrass		Giant reed		RCG		Cardoon		Willow		Poplar		Eucalyptus	
Country	**Yield**	**cost**	**Yield**	**cost**	**Yield**	**cost**	**Yield**	**cost**	**Yield**	**cost**	**Yield**	**cost**	**Yield**	**cost**	**Yield**	**Cost**
AL	18.2	858	13.6	1042	18.7	1712	10.6	2222	11.6	960	16.1	2115	15.0	1563	13.0	831
AT	12.1	141	9.0	154	12.7	222	7.6	240	8.0	181	12.0	215	10.1	228	8.8	131
BA	17.9	353	13.3	411	18.1	918	10.1	1105	11.3	349	15.0	1193	14.6	775	12.6	297
BE	12.0	63	8.9	70	12.2	80	7.6	76	7.7	103	11.6	60	10.0	68	8.5	78
BG	17.9	1297	13.4	1470	19.5	2068	9.1	2341	12.0	1333	13.8	2197	14.0	2480	13.6	1164
CY	20.4	4062	16.1	7033	26.9	7635	9.6	6733	16.7	6670	14.6	6224	14.8	7549	17.1	7054
CZ	11.8	36	8.8	33	12.8	130	7.8	125	8.0	91	12.3	124	9.9	148	8.9	75
DE	11.7	81	8.7	95	12.5	531	7.6	585	7.8	363	12.0	536	10.0	619	8.7	272
DK	10.2	113	7.7	133	10.7	140	6.4	152	6.8	179	10.8	93	8.5	115	7.5	122
EE	8.5	37	6.4	28	8.9	49	5.5	33	5.7	48	8.6	35	7.2	41	6.3	46
EL	20.2	3509	15.8	4885	25.1	5372	9.4	5744	15.3	4059	14.2	5380	14.8	6403	16.8	4033
ES	19.7	2757	15.1	3691	22.9	4293	10.0	4852	14.1	3273	15.0	4480	15.1	4990	15.5	3369
FI	7.2	100	5.4	111	7.4	172	4.6	164	4.8	192	7.7	117	6.1	141	5.2	129
FR	15.0	602	11.2	657	15.7	1250	8.8	1486	9.7	688	13.3	1469	12.2	1364	11.0	583
HR	16.5	702	12.5	670	18.2	1203	8.7	1552	11.2	545	13.0	1537	13.1	1383	12.7	473
HU	16.0	904	11.9	1005	17.4	1542	8.8	1841	10.8	893	13.3	1749	13.0	1820	12.2	753
IE	9.0	95	6.8	106	9.0	123	6.3	111	5.8	149	9.6	79	8.3	89	6.3	109
IT	17.5	1839	13.4	1981	20.0	2495	8.6	3486	12.3	1566	13.0	3265	13.1	3476	13.8	1603
KS	14.1	724	10.4	769	15.2	1286	9.1	1165	9.4	769	15.0	1159	11.4	1416	10.5	570
LT	10.0	43	7.5	39	10.5	57	6.1	47	6.7	56	10.2	35	8.0	42	7.4	41
LU	11.3	66	8.5	72	12.5	83	7.6	79	7.8	104	12.0	55	10.0	64	8.7	68
LV	9.5	33	7.1	24	9.9	44	5.8	26	6.3	40	9.5	30	7.7	36	6.9	38
MD	15.9	559	11.8	541	17.4	997	8.7	1048	10.8	485	13.6	1069	12.6	1157	12.1	424
ME	16.2	681	12.1	698	17.7	1233	10.6	1296	11.0	687	16.1	1379	14.1	1290	12.4	598
MK	18.0	1152	13.4	1297	19.3	1816	9.8	2204	11.8	1219	14.7	2066	14.4	2170	13.4	1090
MT	18.4	3664	14.3	5802	24.0	5858	8.5	6132	14.8	5038	12.8	5324	13.1	6443	15.3	4975
NL	11.1	178	8.3	226	11.7	196	7.3	256	7.4	285	11.4	153	9.6	178	8.2	201
PL	11.2	40	8.4	36	12.2	72	7.3	70	7.7	64	11.7	65	9.4	78	8.6	55
PT	19.5	2115	15.0	2122	22.8	2374	9.2	3977	14.1	1506	13.8	3813	14.3	4026	15.7	1898
RO	15.1	660	11.3	749	16.4	1194	8.5	1356	10.2	769	13.2	1309	12.3	1456	11.4	652
RS	16.4	989	12.2	1141	17.6	1703	8.9	1976	10.9	1023	13.4	1891	13.2	2009	12.3	898
SE	7.9	93	6.0	101	8.2	122	5.2	109	5.3	152	8.6	75	6.8	92	5.8	106
SI	13.9	62	10.3	71	14.6	75	8.4	93	9.1	104	13.0	53	11.5	57	10.2	60
SK	13.7	546	10.2	577	14.9	1080	8.4	1280	9.3	672	13.2	1256	11.3	1343	10.4	553
TR	19.3	2490	14.6	3096	21.6	3785	10.3	4432	13.2	2889	15.9	4059	15.1	4669	14.8	2573
UA	13.7	24	10.2	18	14.6	31	8.1	19	9.2	27	12.8	22	11.2	25	10.2	25
UK	10.2	72	7.6	78	10.6	206	6.9	179	6.7	177	10.8	116	9.0	193	7.4	131

Ringraziamento

Innazitutto vorrei ringraziare a miei cari amici e colleghi per il importante sostegno e suggerimenti che hanno reso possibile la realizzazione di questo lavoro:

- Un ringraziamento infinito a voi carissimi Imma, Filippo e Nocito.

- Ai colleghi di Wageningen, Dott.ssa Berien Elbersen, Igor Staritsky, Raymond Schrijver e Kees van Diepen per i loro consigli e per tutta la conoscenza che grazie a loro ho acquisita.

- Ai colleghi di Bologna, Prof. Andrea Monti, Nicola di Virgilio, Carla Lambertini e Walter Zegada per i loro preziosi suggerimenti.

A tutte quelle persone che in un modo o nell'altro hanno contribuito alla realizzazione del mio studio.