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REVIEW ARTICLE

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Abstract The global energy consumption was 540 EJ in 2010, representing an increase of about 80 % from 1980. Energy demand is predicted to grow more than 50 % by 2025. Fossil fuels will supply about 75 % of the future energy demand in 2030–2050 if there are no significant technological innovations or carbon emission constraints. This will induce in a substantial increase of CO_2 atmospheric concentration and, in turn, adverse climatic impacts. A solution to this issue is to replace fossil fuels by renewable fuels such as biomass. For instance cultivated woody biomass shows many advantages such as allowing multiple harvests without having to replant. Poplar, eucalyptus, salix, paulownia and black locust are common examples of woody biomass. Here we review the current situation and future tendency of renewable energy focusing on solid biomass in Europe and Spain. We also discuss the potential production for short-rotation plantations in the bioenergy sector and existing constraints for the implantation in Spain in a sustainable context. Countries with low biomass resources and high targets for renewable electricity may have to depend on imported solid biomass, whereas countries with wide solid biomass resources benefit from international markets. The expansion of short-rotation plantations is much lower than expected in some countries such as Spain.

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Keywords Woody biomass · Energy crops · Short-rotation plantation · Poplar · Willow · Eucalyptus · Paulownia · Robinia

Abbreviations

Mtep	Million-ton equivalent of petroleum
EJ yr^{-1}	ExaJoules per year (prefix exa=$\times10^{18}$)
Mtoe	Megatonnes of oil equivalent
Mt	Megatonnes
MW	MegaWatt
MWh	MegaWatt hour
PJ	PetaJoules (prefix peta=$\times10^{15}$)
TWh	TeraWatt hour (prefix tera=$\times10^{12}$)
Tg	Teragrammes
GJ ha^{-1}	GigaJoules per hectare (prefix giga=×10)
$t_{wb}h^{-1}$	Tonnes wet basis per hour
t_{DM}	Tonnes of dry matter
gt ha^{-1}	Green tonnes per hectare
gt SMH^{-1}	Green tonnes per schedules machine hour

Contents

1 Introduction

The emissions related to the use of fossil fuels are the source of global environmental problems and are in many cases irreversible. The current energy system based on fossil fuels is unsustainable, forcing us to seek new alternative energy sources that could mitigate global warming while responding to current and future energy demands. According to the International Energy Agency (IEA), the worldwide demand is expected to increase by 36 % between 2008 and 2035 (International Energy 2010), since energy plays an essential part in the world's present and future development. Global annual energy demand has rapidly grown, from 10,000 to 13,000 Mtep in the past 15 years (García et al. 2012). However, 40 % of the total energy consumption worldwide is based on the use of non-renewable liquid fuels. As stated by the last World Energy Outlook of the International Energy Agency, fossil fuels will remain the dominant energy source in the coming decades, but the use of renewable energy will triple between 2008 and 2035 and its share in the electricity supply will rise from 19 % in 2008 to 32 % in 2035 (International Energy 2010). In this context, energy conservation policies to reduce electricity use, including more efficient appliances, high-efficiency lighting and more responsible energy practices, will also be promoted. In fact, the European Union has set the following objectives for 2020: 20 % of the European Union's total energy supply will come from renewable sources and the European Union's greenhouse gas emissions will be reduced by 20 % with respect to 1990.

In this regard, the best way to guarantee this increasing demand is energy diversification and the promotion of alternative energy sources, which minimize the environmental impact and avoid the dependence on fossil fuels, for which reserves are declining and prices are fluctuating.

Moreover, Europe and particularly Spain still have an excessive dependence on fossil fuel imports. Recently, Spanish policies have been developing a new energy model with legal measures and budgetary consignment. The aim is to encourage the transformation process which is essential to fulfil the European energy objectives: the former Renewable Energy Plan (2005–2010) has now been followed by the Plan of National Action for Renewable Energy (Plan de Acción Nacional de Energías Renovables; PANER) of 2010–2020. This current legal framework aspires to a new model which encourages structural changes in the energy system and the establishment of a new energy culture consciousness of the fact that energy is limited and valuable.

In this context, biomass has traditionally been an important energy source, especially since it is environmentally friendly and renewable. Biomass is one of the major energy sources today, representing 14 % of the world's annual energy consumption (Rosua and Pasadas 2012).

In this sense, the observatory which best describes the situation of renewable energies in Europe (Solid Biomass Barometer 2012) establishes four main types of energy sources within the bioenergy category: (1) solid biomass, (2) biogas, (3) organic fraction from municipal wastes and (4) biofuels. Also, according to Cerda et al. (2008), solid biomass can be divided into:

Primary	From energy crops, which are plant species used specifically to produce biomass for energy. Woody species cultivated under short-rotation systems will be analysed in this paper.
Secondary	Forest wastes (such as resulting from cleaning and pruning), agricultural wastes (olive, grapevine and other pruning material) and industrial forest wastes (sawdust, olive stones, nut husks, etc.).

Bioenergy plantations will predictably become the primary source of biomass for energy purposes on a global scale. More specifically, the use of forest wood has been identified as a potential source of biomass for energy in several studies (up to about 115 EJ yr^{-1} in 2050) (Hämäläinen et al. 2011). The interest of biomass has been focused for producing heat and electricity production; however, the new technologies and research results, together with the increasing cost of common fuels, have currently driven interest to liquid biofuel production.

Among cropping systems, short-rotation plantations (SRPs) are of high interest, since they utilize short return times instead of traditional wood plantations, which require longer year intervals. Short-rotation coppices are wood systems in which fast growing tree species (*Populus* ssp., *Eucalyptus* sp., *Salix* sp., *Paulownia* sp. and *Robinia* sp.) are grown under intensive agricultural practices (weed control, fertilizers application and irrigation) to achieve high biomass yields (Fig. 1). Basically, trees are grown either as single stems or as coppice systems with rotation periods under 15 years and profitable annual woody production, since trees are cut every period of rotation and they are left to re-grow.

Fig. 1 Short-rotation plantation systems with fast growing *Eucalyptus* sp. grown under intensive agricultural practices (weed control, fertilizers application and irrigation) (**a**) and *Populus* ssp. trees during harvesting operations in SE Spain (**b**)

Renewable energy from biomass has enormous growth potential in Spain; in fact, it is the renewable energy that has shown economic results based on the profits generated, given its capacity to create jobs, develop rural areas and help improve the environment.

The production of bioenergy crops will most likely continue to place significant demands on land resources worldwide, despite that non-food oil crops and lignocellulose crops (e.g. short-rotation woody crops) will be introduced in the medium to long term. To meet global demands for biofuels, the International Energy Agency has predicted that 65 million ha of land will be necessary by 2030 and 105 million ha by 2050 (International Energy Agency 2011). Various studies have proposed a relation between bioenergy policies, demand for cropland and negative land use changes, especially deforestation (Searchinger et al. 2008). To date, a land use change due to bioenergy demand in the European Union has not been considerable; however, future bioenergy demand will influence land use in the European Union according to Banse et al. (2011). In EU-15, the demand for cropland and pasture for food production is expected to decrease, and then "surplus" agricultural land would become available for future bioenergy crop production, as stated by Fischer et al. (2010). Areas dedicated to lignocellulose crops are expected to increase considerably in the mid to longer term (Rowe et al. 2011). Furthermore, since land is limited in the European Union, the increasing biofuel demand is starting to have effects on land resources outside the region. Apart from greater vegetable oil imports, several European companies have claimed over 5 million ha of land in South America, Southeast Asia and Africa for biofuel production (Matondi et al. 2011). Countries such as Spain have started importing soy bean biodiesel from Argentina. Thus, to reach the biofuel European Union requirements, EU countries will depend more on imported feedstock and processed biofuels from countries where agricultural expansion is possible, such as Brazil, Argentina, Ukraine, USA, Canada and others (Laborde 2011). As a result, the conversion of primary forests, savannas and grasslands to bioenergy crop fields will probably occur in these regions.

Some more recent studies have predicted the required land use changes to meet the European Union bioenergy demand. In this context, the European Union member states adopted in June 2010 the National Renewable Energy Action Plans (NREAP), proposed by the European Commission, which included objectives for the share of energy from renewable energy sources in electricity, heating and transport, as well as measures to take to reach these targets. In these plans, the European Union countries proposed two scenarios for energy use until 2020: the "reference scenario", which includes only the energy-efficiency measures adopted before 2009; and the "additional energy-efficiency scenario", which takes into account all energy measures adopted after 2009. In this sense, Scarlat et al. (2013) quantified the impact of the 2020 bioenergy targets on land use changes, based in four scenarios. This study reveals that the land used in the European Union for bioenergy would range from 13.5 to 25.2 Mha in 2020, representing between 12.2 and 22.5 % of the total arable land used and 7.3 and 13.5 % of the agricultural area in use. In addition, for the NREAP scenario, about 17.4 Mha would be used for bioenergy production, accounting for 15.7 % of arable land and 9.4 % of agricultural area in use. The demand for biofuels would lead to an increased generation of coproducts, replacing conventional fodder for animal feed, taking into account that the land used for bioenergy would range between 8.8 and 15.0 Mha in 2020 in the various scenarios. This represent between 7.9 and 13.3 % of the total arable land used in the European Union and between 4.7 and 8.0 % of the agricultural area in use. When coproducts are considered, about 10.3 Mha would be used for biofuels, bioliquids and bioenergy production, representing 9.3 % of arable land and 5.6 % of agricultural land. The targets pursued for 2020 in terms of land use requirements differ for each state member. Specifically in Spain, in the NREAP baseline scenario, land use will reach 2.6 Mha.

Therefore, the objectives of this review were the following: (1) to analyse the current situation and future tendency of biomass energy focusing on solid biomass in Europe and Spain and (2) to search the potential production for short-rotation plantations (SRPs) in the energy sector and the main existing constraints for their implantation and extension in Spain. In particular, this review focuses the potential of poplar, eucalyptus, paulownia, willow and robinia or black locust cultivation for woody biomass production under short-rotation systems in order to meet the growing demand of biofuels in the coming decades in an energy farming context.

2 Bioenergy market

2.1 The global and European context

Despite the small proportion of modern bioenergy to the total global energy mix, biomass will in the long term contribute much more significantly to the global energy supply. Many studies have estimated the potential to harvest energy from biomass sources. Berndes et al. (2003), reporting information related to this issue, described far different estimates for biomass production in the global energy supply, from 100 EJ yr^{-1} to more than 400 EJ yr^{-1} for 2050. In accordance with Hoogwijk et al. (2005), in the most optimistic situations, the biomass will meet the current energy demand without competing with food, wood or biodiversity. Dornburg et al. (2008) have analysed the effects of food supplies, water use, biodiversity, energy demands and agro-economics on the potential of biomass for energy supply. They concluded that 250 EJ is available (water stress areas and/or with high biodiversity excluded). In addition, regions such as Latin America, Sub-Saharan Africa, and Eastern Europe, Oceania and East and Northeast Asia will presumably be net exporters, while OCDE and Southeast Asia will be the main importers (Heinimö and Junginger 2009). Other studies related to these predictions have been reported by de Vries et al. (2007), who predicted a global potential for primary bioenergy range between 0 and 1550 EJ yr^{-1}. Also, other ranges have been estimated using different methodologies, with more pessimistic projections of 0 to 648 EJ yr^{-1} by Wolf et al. (2003), and optimistic values from 367 to 1548 EJ yr^{-1} by Smeets et al. (2007).

2.1.1 Solid biomass in European Union countries

According to EurObserv'ER (Solid Biomass 2012), the primary energy production in the European Union has increased at an average rate of 3.8 % since 2000, when it was 52.5 Mtoe, and in 2012 it raised to 82.3 Mtoe. The total consumption of solid biomass primary energy was in 2012 of 85.7 Mtoe (Table 1). By analysing the databases of the statistics of Eurostat (total energy consumption, total electricity available for consumption and share of renewable energy in fuel consumption of transport), it is important to point out that the main "energy consumers" in EU-28 are Germany (19 % respecting to total), France (15.6 %), the UK (12.0 %), Italy (9.7 %) and Spain (7.6 %), and the main "producers of electricity available for consumption" are Germany (18.1 %), France (14.9), the UK (11.0 %), Italy (10.2 %) and Spain (8.3 %). Also, with respect to the share of renewable energy in fuel consumption of transport, the most sustainable countries are Sweden (12.6 %), Austria (7.7 %), France (7.1 %), Germany (6.9 %) and Poland (6.1 %). By analysing these three databases and Table 1 from this paper, we can remark the following points regarding certain countries:

- Sweden, in spite of not being one of the main energy producers, is the first one in the share of RE in transport and also the third in primary energy production of solid biomass (Table 1).
- Spain is one of the main consumers and producers; however, in the share of renewable energy in transport, it is one of the lowest (0.4 %). Therefore, it occupies the sixth position in primary energy production of solid biomass, which gives an idea about the putting in place has in Spain.
- Czech Republic occupies only the 12th position in the production of electricity for consumption; however, it is the first one in renewable energy share in transport and the third in primary energy production of solid biomass.
- Austria, in spite of occupying the second position in renewable energy share in transport, is not one of the first

Table 1 Primary energy production and consumption of solid biomass in the Europe (2011–2012)

Country	2011		2012	
	Production	Consumption	Production	Consumption
	(Mtoe)			
Germany	11.054	11.054	11.811	11.811
France	9.089	9.089	10.457	10.457
Sweden	8.934	8.934	9.499	9.499
Finland	7.607	7.593	7.919	7.945
Poland	6.350	6.350	6.851	6.851
Spain	4.812	4.812	4.833	4.833
Austria	4.537	4.681	4.820	5.029
Italy	3.914	5.127	4.060	5.306
Romania	3.476	3.459	3.470	3.470
Portugal	2.617	2.617	2.342	2.342
Czech Republic	2.079	1.959	2.153	2.057
United Kingdom	1.623	2.240	1.810	2.473
Latvia	1.741	1.121	1.741	1.121
Denmark	1.499	2.384	1.489	2.473
Hungary	1.429	1.435	1.429	1.435
Belgium	1.105	1.516	1.105	1.516
Netherlands	1.000	1.322	1.099	1.350
Estonia	0.939	0.794	1.012	0.814
Greece	0.940	1.036	1.000	1.136
Lithuania	0.983	0.914	0.992	1.003
Bulgaria	0.834	0.961	0.974	1.275
Slovakia	0.784	0.760	0.717	0.717
Slovenia	0.566	0.566	0.560	0.560
Ireland	0.190	0.203	0.195	0.212
Luxemburg	0.046	0.042	0.048	0.043
Cyprus	0.005	0.012	0.005	0.012
Malta	0.001	0.001	0.001	0.001
EU	78.152	80.983		85.689

Note the increasing tendency from 2001 to 2012 (more than doubled over the 1990–2010). Imports from other countries make up the difference between production and consumption (Solid Biomass 2012)

countries supporting the use of biomass for energy production.

– Poland occupies the sixth position in energy consumption (5.82 %) and the seventh in the production of electricity; however, it is one of those in the main positions (fifth) in primary energy for solid biomass

In 2011, there was a decrease in primary energy production from solid biomass because of the abnormal warm winter. However, the increasing tendency has come up again in 2012. In fact, it was more than doubled over the 1990–2010 period (39.5 Mtoe produced in 1990). In 2012, the consumption of wood pellets in the European Union was 15.1 million tonnes, with 10.5 million tonnes being the production in this year, which means that the European Union must import around 30 % of its consumption. The main producers in the European Union are Germany, Sweden, Latvia and Austria. The main suppliers of this raw material for the European Union are the USA (with a total of 1.764 million tonnes exported in 2012), Canada (with 1.346 million tonnes), Russia (0.637 million tonnes), Ukranie (0.217 million tonnes) and Belarus (0.112 million tonnes). These imports from these mentioned countries make up the difference between production and consumption.

The EurObserv'ER report of solid biomass assumes that the processing sector of heat-production data tends to match sales to district heating networks and concludes that sales were down by 7.5 % in 2011 for 7 Mtoe of production (Solid Biomass 2012). Most of this heat, 60.8 % in 2011, was produced in cogeneration, i.e. combined heat and power (CHP) plants (Fig. 2). They estimate that the final energy consumption in 2012 that accounts for most heat consumption (residential and industrial segments) is 68 Mtoe, a 4.6 % year-on-year slide. According to this, countries such as Spain, Portugal or Greece have relatively high heat consumption; however, district heating production is null.

In general, biomass trade has rapidly grown in recent years. Countries with low biomass resources and high targets for renewable electricity and heat and liquid biofuels may have to depend on imported solid biomass. On the other hand, countries with wide solid biomass resources are discovering the potential profit of international markets, and some countries have built wood pellet factories with the sole purpose of export. According to the EUBIONET III project (European bioenergy network), only 48 % of the annual biomass potential is currently used in the EU-24 and Norway. EUBIONET III has calculated that the potential is 6577 PJ (157 Mtoe), of which 67 % is from woody biomass. Thus, in compliance with EUROBIONET conclusions, the following countries have the lowest total annual biomass resources (<100 PJ): Belgium (50 PJ), Bulgaria (42 PJ), Denmark (34 PJ), Estonia (48 PJ), Slovenia (53 PJ), Lithuania (47 PJ), Slovak Republic (72 PJ), the Netherlands (77 PJ) and Greece (74 PJ). On the contrary, Germany (1080 PJ), Sweden (841 PJ), Spain (588 PJ), France (574 PJ), Italy (484 PJ) and Finland (428 PJ) are the European Union countries endowed with the richest biomass resources.

Hoefnagels et al. (2014) describe the development of a GIS tool in combination with the European renewable energy model Green-X. According to the 2020 scenario, biomass from domestic origin will be the most important source of bioenergy (91–93 % in 2020) and trade of solid biomass will become very important. Assuming a current scenario, the obligatory renewable energy targets will not be achieved; however, the trade of solid biomass will increase up to 451 PJ in 2020 (Hoefnagels et al. 2014). If taking into account the scenario that assumes that these targets will be met in

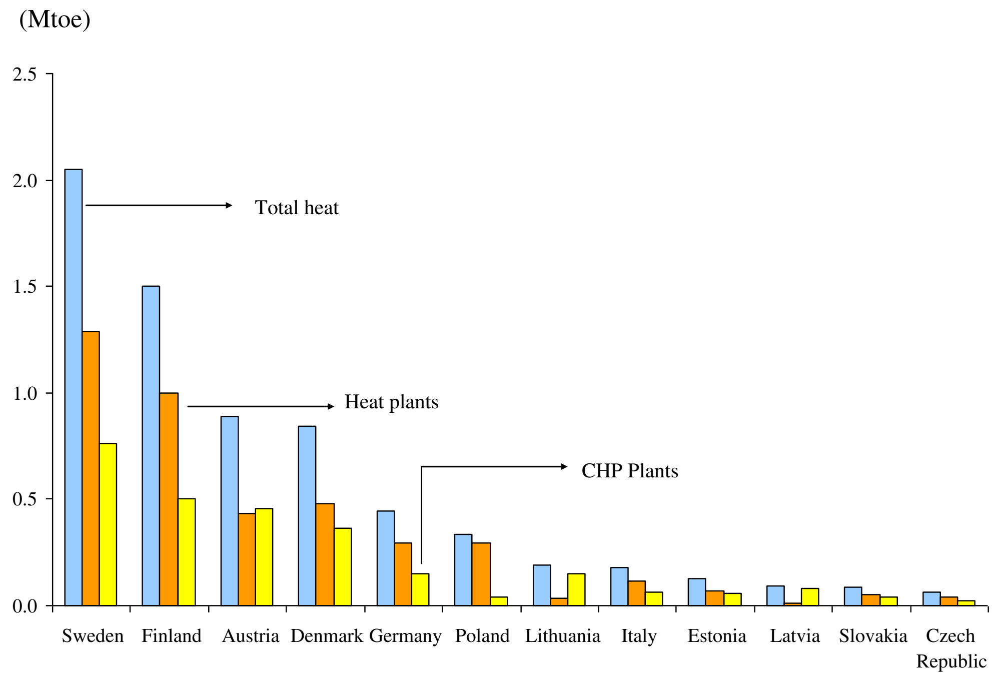


Fig. 2 Heat production from solid biomass in the European Union in 2011 in the transformation sector (Solid Biomass 2012). *CHP* combined heat and power. Note: Main producers are Sweden, Finland, Austria and Denmark. A total of 60.8 % of heat production (2011) was produced in cogeneration. Countries such as Spain, Portugal or Greece have relatively high heat consumption; however, the district heating production is null

2020, traded solid biomass is projected to increase to 440 PJ and to 506 PJ without the sustainability criteria. The role of internationally traded biomass sources is predicted to be very important. In total, intra-EU and extra-EU trade of solid biomass will increase to between 373 and 506 PJ, equivalent to 21–28 Tg of wood pellet. The highest growth is predicted for imports from outside the EU-27. According to the predictions of this study, Germany, France and Sweden will remain the largest consumers of biomass (44 % of the total primary biomass demand). By 2020, the main exporting countries will be Bulgaria, Czech Republic, Hungary, Poland, Slovakia and Slovenia, and the key regions on intra-EU biomass imports will be Germany (mainly from Poland and Czech Republic) and Austria (from Slovenia and Hungary). The most part of the countries of the European Union will import solid biomass from outside the European Union in 2020, with Germany, France, Belgium, Italy and the UK being the most important extra-importers.

However, in spite of the great potential for SRP in the European Union countries, the area devoted to these plantations has remained almost stable in certain countries, such as Sweden, with its increase being lower than predicted. In this sense, Dimitriou et al. (2011) carried a survey where 175 growers participated to search the reasons why the development of willow short-rotation plantations was not expanded. They found the following reasons: often farmers choose marginal lands for SRP, with a lower yield due to lower quality soils; lack of previous experience and therefore inadequate management; and finally little engagements of farmers.

In this same context, Schweier and Becker (2013) analysed the economy of a typical SRP production chain in Germany. They concluded that the prices for the establishment and cultivation and transport for the fresh wood chips were not competitive with those for annual crops, neither the subsidies obtained by the Common Agricultural Policy (CAP).

Thus, it will be necessary to promote the installation and extension of SRP by means of the proposed stimulation measures suggested by the above mentioned authors: (1) implementation of policies which stimulates biomass production on agricultural soils from SRP, (2) development of expert advice which support farmers on management cultivation, (3) research in modern irrigation systems to improve plant-available water balance, (4) investment and research in plant breeding programmes (which are already being implemented, e.g. Verlinden et al. (2013)) and (5) increasing the value adding process by including the drying of fresh chips from SRP systems.

2.2 Potential expansion of solid biomass in Spain and Andalusia (S Spain)

As mentioned above, Spain is still heavily dependent on fossil fuels, whose consumption in 2012 being 42 % of the total primary energy of the country and much higher than the average European consumption (24 %) (IDAE Statistics 2012). However, there has been a considerable increase in the share of renewable energy sources from 2004 to 2011 (0.8 to 5.9, respectively). Spain occupied the sixth position for this share, after Sweden, Austria, Poland and Germany (8.8, 7.6, 6.5 and 6.1 for 2011, respectively). A considerable increase in renewable energy importance in the energy mix occurred because in 2009, for the first time, energy from renewable

Table 2 Primary energy consumption and total percentages in Spain in 2012

Source	Consumption (ktoe)	Respect to total (%)
Coal	14,986	11.6
Fuel	54,108	41.9
Natural gas	28,241	21.9
Nuclear	15,993	12.4
Renewable energies	15,778	12.2
Respect to total of renewable energy (%)		
Hydro	1763	11.2
Wind	4227	26.8
Biomass	4831	30.6
Biogas	260	1.6
Solid urban waste	159	1.0
Biofuels	2124	13.5
Geothermal	18	0.1
Solar	2397	15.2

Source: IDAE. In 2012, renewable energy share was higher than coal, the main source being fuel. Among the renewable energies, biomass has the highest share

sources was higher than energy generated from coal. In 2012, this tendency was the same; coal and renewable energy sources representing 11.6 and 12.2 %, respectively, of the total of energy consumption (IDAE Statistics 2012; Table 2). With respect to renewable energy sources, this 12.2 % was distributed among biomass (30.6 %), wind (26.8 %), solar energy (15.2 %), hydro energy (11.2 %), biofuels (13.5 %), biogas (1.6 %), solid urban waste (1.0 %) and geothermal energy (0.1 %). The renewable energy sector in 2010 created approximately 130,000 jobs, the most being in the wind, solar photovoltaic and biomass sectors (Fig. 3). The distribution of these jobs according to their main activity is equipments manufacture (37.6 %), installation and construction (16.9 %), service and project developments (18.3 %), commercialization and sale of equipment (10.3 %), research and development (4.5 %), maintenance (12.0 %) and education (0.4 %) (IDAE 2011).

Gómez et al. (2011) analysed the Spanish case based on nine different scenarios according to different economic and strategic criteria. This study highlights that the objective of the 20 % energy supply target implies that approximately 45 % of the electricity should be renewable by 2020 (assuming that biofuels contribute 10 % to the final energy consumption in the transport sector). In line with this and in relation to solid biomass, Spain occupies the sixth position in primary energy production from solid biomass (after Germany, France, Sweden, Finland and Poland; Fig. 4a) (Solid Biomass 2012). However, if these amounts of energy production are expressed as primary energy production of solid biomass by the tonne of oil equivalent (toe) per inhabitant in the European Union, Spain occupies the 18th position with a rate of 0.104 in 2011, which is lower than the average rate for European Union (0.157 in 2011) and far lower than Finland (1.391), Sweden (0.867) or Latvia (0.784), which are the highest producers by toe per inhabitant (Solid Biomass Barometer 2012). Figure 4b also shows the gross electricity production from solid biomass in UE-27 (Cyprus and Malta have zero production). Spain is the 9th producer (2.937 TWh), quite far from the highest producers: Germany, Finland and Sweden, with 11,539, 9968 and 9.641 TWh, respectively.

In the environmental analysis of the “Plan de Energías Renovables 2011-2020”, results from a study on biomass

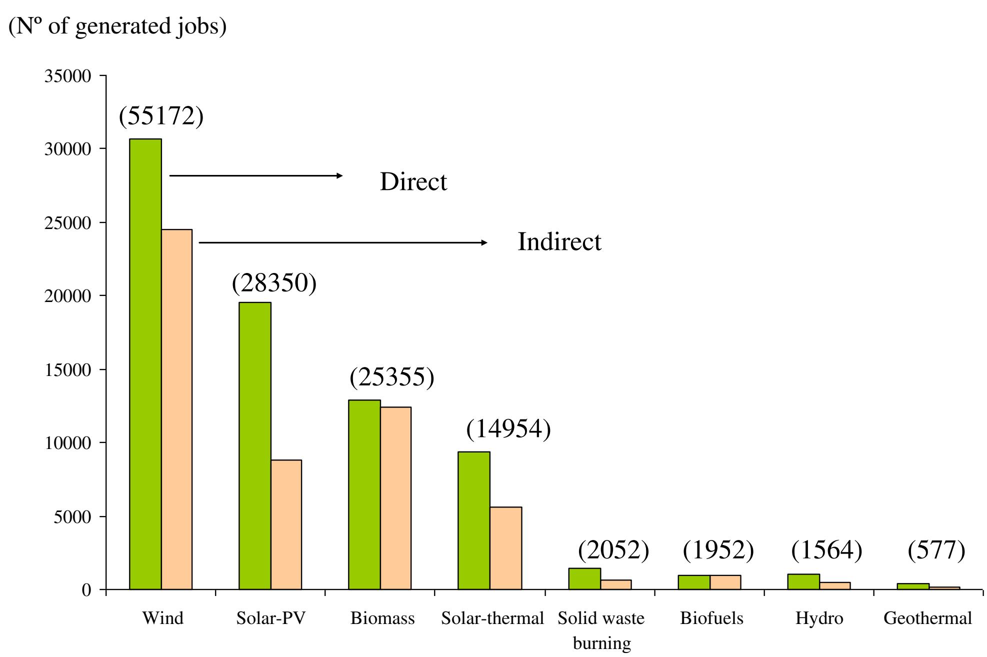


Fig. 3 Jobs generated, direct and indirect, from renewable energy source in Spain in 2010. *Values in brackets* are total jobs generated. The renewable energy sector in 2010 created approximately 130,000 jobs in Spain, the most being in the wind, solar photovoltaic and biomass sectors. Source: IDAE Statistics (2012)

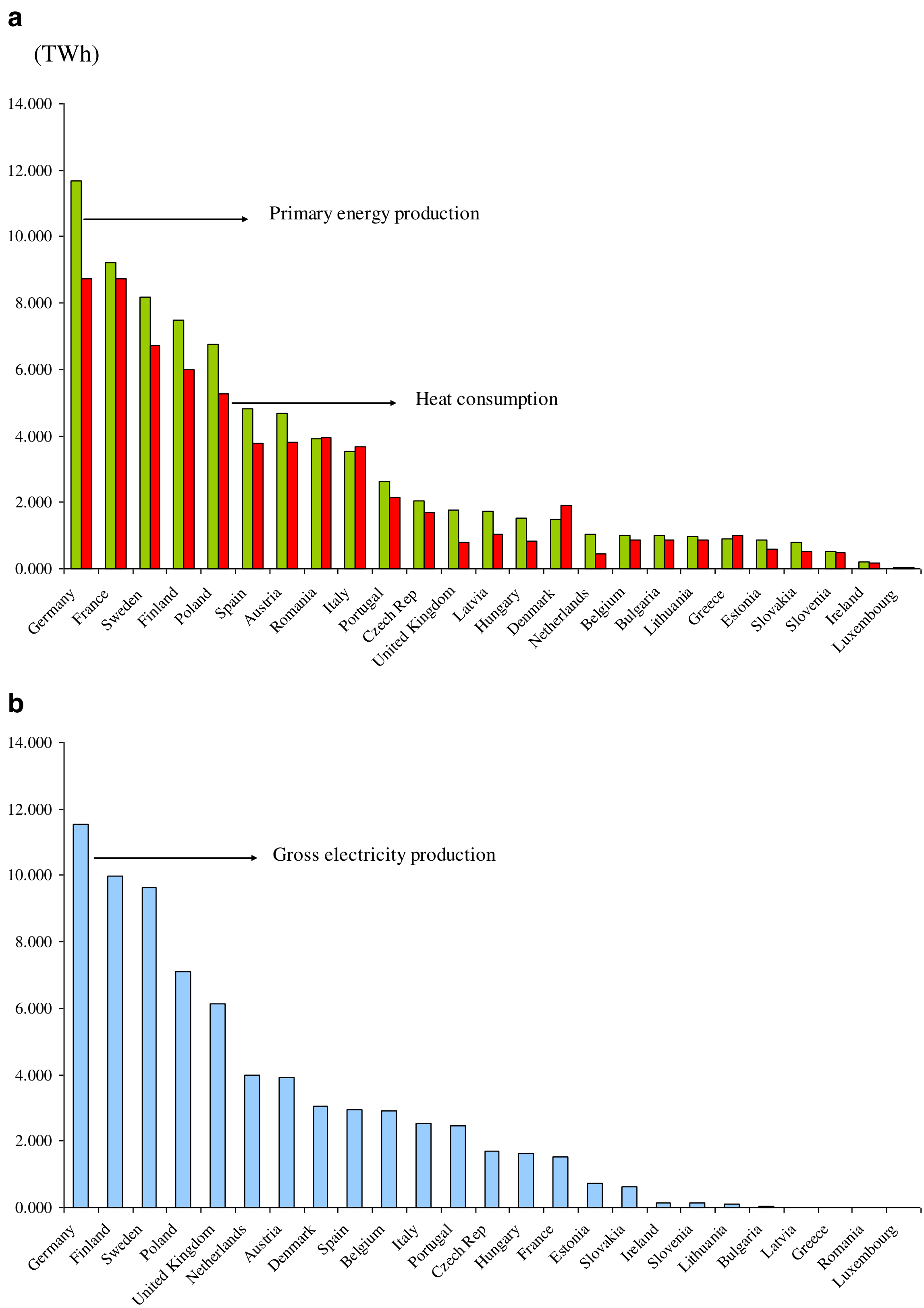


Fig. 4 Primary energy production and heat consumption (**a**) and gross electricity production (**b**) from solid biomass in 2011. Source: Solid Biomass Barometer (2012). Note that Spain occupies the sixth position in primary energy production from solid biomass. Spain is the ninth producer in gross electricity production, quite far from the highest producers: Germany, Finland and Sweden

potential of non-industrial origin in Spain are presented: energy crops, herbaceous or woody, forest and agricultural wastes (Table 3). In this report, the available areas for biomass energy crops were determined under certain criteria, taking into account the non-interference with the food market, the sustainability of production markets, and the existing limitation in the irrigation water. From this study, certain areas are excluded: prairies with traditional extensive feedstock use. According to this analysis, potential biomass in Spain for energy purposes is approximately 11-fold the energy used in 2006. This potential is shared among agricultural biomass (36.9 %), biomass crops establishment in agricultural areas (24.4 %), forest biomass (21.4 %) and biomass establishment in forest areas (17.3 %).

The woody energy crops under short-rotation management are not widespread in Spain, and in particular in Andalusia (S Spain), its area is limited to experimental plots (AAE 2011). According to García et al. (2014), the most important constraints for the further development of the biomass sector are the absence of continued government support, the inadequate management of supply, transport and storage, and the lack of an established commercial strategy for biomass. In this region of SE Spain, biomass firms work mainly with wood pellets and olive pits, and their distances in transport are often considerable, making it more expensive. In an immediate future, these enterprises will have to develop a strategy of distribution which guarantees the supply of pellets with competitive prices. In this sense, the regional government encourages its experimentation and implementation through different studies for the evaluation of the biomass production from woody as well as from herbaceous energy crops (Junta de Andalucía 2012). This is especially the case of woody crops, including short-rotation plantations, which appear to constitute one of the best prospects for farmers. In this context, a strategic project was begun for the demonstration of viability and the energy-production development with woody crops, assessing the harvest of energy with short-rotation plantation systems (Junta de Andalucía 2012). According to this, the most suitable fast-growing tree species for irrigated short-rotation plantations were poplar (*Populus* spp.), paulownia (*Paulownia fortunei* and *Paulownia tomentosa*) and eucalyptus (*Eucalyptus* spp.). This latter species could also be adapted to rainfed conditions. By contrast, willow (*Salix* sp.) and black locust (*Robinia* sp.) have not been studied in Spanish environments.

The proper areas for poplar cultivation are the fertile plains next to the rivers, being periodically flooded as in the case of Vega (cultivated fields) of Granada (Spain). Poplar cultivation is limited primarily to irrigated areas, while eucalyptus can be grown as an energy crop without irrigation. Many species adapted to Andalusia as energy crops for solid biofuels are suited to short-rotation plantations that are generally recommended to be grown in low-lying areas without cold winters.

Eucalyptus and poplar have traditionally been used for wood production, pulp and veneer, but for some years, it has been used for energy generation. The available poplar clones are those traditionally used for veneer: NNDV, I0MC, Triplo, I0214, Viriato, Beaupré and others that could be used for energy farming under SRP system.

Spain has a large area devoted to poplar wood production with more than 135,710 ha, of which about 8434 ha are located in Andalusia (MAGRAMA 2012). In relation to eucalyptus, according to Veiras and Soto (2011), during the last few decades, its area devoted to plantations has decreased in Spain and Andalusia, amounting to 760,000 and 155,934 ha, respectively, most for pulp production.

On the other hand, RWE Innogy Iberia, the subsidiary of RWE Innogy on the Iberian Peninsula, is operating its first energy crop plantation in Villamartín, close to Cadiz in Spain (RWE 2013). On the 235-ha field, more than 390,000 paulownia trees were cultivated in 2009. According to the RWE (2013), the energy crop plantation in Villamartin was established to guarantee part of the feedstock supply for a planned 10-MW power plant project in the area of Lebrija, Andalusia, in the coming years. This plantation may be the

Table 3 Available potential for expanding biomass in Spain

Source		Potential available biomass (t yr^{-1})	Average price (€t^{-1})	Biomass consumption (t yr^{-1})
Existing forest areas	Forest wastes	2,984,243	26.59	5,545,287
	Entire tree	15,731,116	43.16	
Agricultural wastes	Herbaceous	13,586,759	19.98	478,011
	Woody	18,605,756	19.98	1,912,046
Grasslands available for agricultural uses		15,874,572	45.62	0
Woody areas available for agricultural uses		5,457,812	34.73	0
Woody areas available for forest purposes		15,072,320	42.14	0
Total biomass potential in Spain		87,312,398	–	7,912,046

Data in tonnes in fresh weight biomass (45 % water). Source: Informe de Sostenibilidad Ambiental del Plan de Energías Renovables 2011–2020. Note that potential biomass in Spain for energy purposes is approximately 11-fold the energy used in 2006. For more details of how this quantities of available potential biomass are calculated, see also Herranz (2008) and Cerdá (2012) largest area devoted to paulownia short-rotation coppices cultivated in Spain. However, possibilities of willow and locust as woody energy crops have not yet been explored, these trees being widespread on Spanish riverbanks and river valleys (Ciria 2011).

3 Wooden biomass potential for sustainable energy farming

As stated above, bioenergy can originate from many sources, from organic waste to annual and perennial crops established for this purpose. Figure 5 shows the biomass resources estimated by Esteban and Carrasco (2011). In total, there are 99.12 Tg yr^{-1} of potential biomass resources in the 11 European Union countries considered in that study (including Norway). After technical and environmental restrictions, the available resources are estimated to be 49.28 Tg yr^{-1} (49.71 % of the estimated biomass potential). Most forest biomass is located in northern European Union countries considered (63.07 % of the potential and 62.95 % of the available resources). Potential resources in the five Southern European Union countries studied are calculated to be 36.60 Tg yr^{-1}. The available resources estimated after the application of restrictions was 104.37 Tg yr^{-1}. These authors estimated that in the central and northern countries studied, the total biomass resources are 188.05 Tg yr^{-1}, of which 125.53 Tg yr^{-1} are agricultural wastes and 62.52 Tg yr^{-1} are forest biomass. The available forest resources are 31.6 Tg yr^{-1}, with Sweden being the country with the highest amount of resources (Esteban and Carrasco 2011). Furthermore, they evaluated the harvesting costs to identify suitable plant locations. They found that the highest harvesting costs were for Italy (33.2 and 74.0€Mg^{-1}, respectively, for agricultural and forest wastes) and the lowest for Portugal (21.4 and 27.4€Mg^{-1}). In northern and central European Union countries, the highest biomass collection costs were calculated for Norway, 37.6 and 27.8€Mg^{-1}, and the lowest for Poland, 15.6 and 11.5€Mg^{-1}, for agricultural and forest wastes, respectively.

Particularly, short-rotation woody crops for energy purposes will presumably be the most important in biomass feedstock proportion and will reduce the greenhouse gas emissions by some 80–90 % compared to the fossil fuel baseline (Djomo et al. 2011). In this context, there are several studies which discuss its financial viability for bioenergy. In the UK, Mitchel et al. (1999) concluded that a stable market for wood chips and government aid are necessary for short-rotation plantations to be feasible at a commercial scale. Ericson et al. (2006) found that willow is a profitable crop in Poland, since the cost production is lower (diesel prices, labour, and fertilizers).

The biomass as a raw material can be used to produce heat and electricity, as stated above. However, without structural changes in the energy system, a negative environmental, economic or social impact can result from the production of biomass energy crops and removal of biomass waste from forest and agricultural systems for energy production. Moreover, unsustainable biomass production would erode the climate-related environmental advantage of bioenergy. Consequently, it is more important than ever to reliably demonstrate that the advantages of biofuels made from biomass

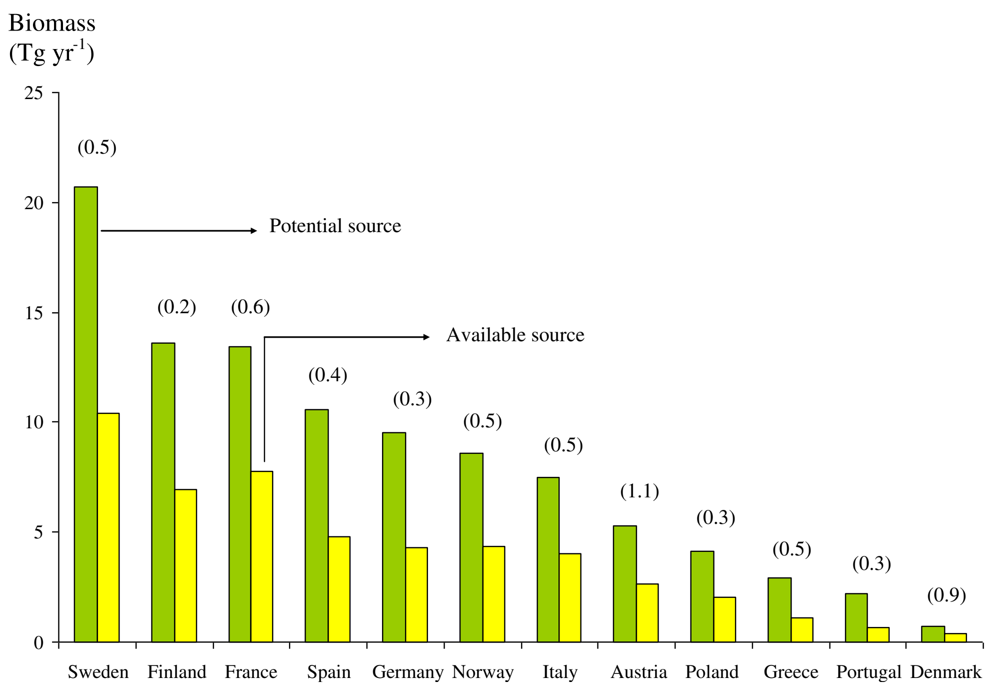


Fig. 5 Biomass resources estimated in the European countries. *Values in brackets* are mean annual productivity values (MAPV, in Mg ha^{-1} yr^{-1}). Esteban and Carrasco (2011) estimated 99.12 Tg yr^{-1} of potential biomass resources in the 11 EU countries. Potential resources in the five southern EU countries studied are calculated to be 36.60 Tg yr^{-1}. Note that potential biomass in Spain is similar to those in strong producers such as Sweden or Finland

exceed the cost of potential environmental damage caused by their production. Thus, sustainable production of biomass for use as biofuels is the major issue in order to increase energy farming.

For investments in sustainability, high standards are needed to incorporate: (i) substantially reduce life cycle greenhouse gas emissions; (ii) protect the environment, including all natural resources; and (iii) enhance market and public acceptance of sustainably produced alternative and renewable fuels. The proposals must explain their environmental implications, reductions in greenhouse gas emissions, better management practices for water usage and collection methods of feedstocks used in production process. Therefore, new measuring methodologies are needed to estimate indirect land use changes resulting from the production of woody energy crops.

Strong variety-dependent differences in growth behaviour can be detected in many SRPs, and therefore the development of new varieties is needed in order to optimize the biomass production for the respective local sites. Particularly, improved clones and varieties that have a low water demand and that are suitable for establishing short-rotation plantations on marginal lands could be developed through plant breeding.

Standards for short-rotation plantation management are also needed, especially to test and demonstrate its sustainability on both a carbon and an energy basis. Farmers need clear guidelines to ensure the establishment of environmentally friendly, sustainable management practices regarding techniques employed during the production process of biomass under the short-rotation plantation system. Thus, the optimisation of a sustainable woody biomass yield from short-rotation plantations requires knowledge of the best-adapted species for a given environment.

In general, Table 4 displays some important approaches for encouraging the energy generation from biomass in agronomic and biological perspective.

Table 4 Approaches to boost the energy production from biomass in agronomic and biological terms for sustainable energy farming

Short-term perspective	Large-term perspective
Identify new plants with outstanding energy production per unit of area	Develop varieties of new energy crops (herbaceous and woody) with high energy yield per unit of area
Identify the pathways of photosynthesis and modes of enhancing solar energy capture.	Determine the cell wall processes and modes of enhancing the carbohydrate pathways
Identify plant genes linked to resistance or tolerance to major biotic or abiotic stress	Introduce genes and develop plant varieties able to withstand certain degrees of biotic and abiotic stress
Identify genetic material with improved soil nutrient uptake and use	Increase yield and crop production efficiency, yield stability in different environments and biomass-crop rotation systems, as well as innovative cropping systems which include non-tillage, double cropping as well as multifunctional land use, marginal land use and low-input systems
Develop studies for understanding symbiotic plant-bacteria associations for atmospheric N fixation for woody energy species	Improve production systems to incorporate standards for atmospheric N fixation
Investigate plant-microorganism associations with growth promotion capabilities	Develop processes and application technologies to introduce growth promoters and N-fixating microorganisms on energy production farming systems
Identify phytohormones, biochemical pathways and substances acting as hormonal bio-activators	Integrate the use of bio-activator substances into biomass production systems
Validate soil C impact on crop waste removal	Develop systems that sequester soil C and enable C reallocation for energy
Foment understanding and demonstrate the potential increase in productivity of new woody crops	Develop optimal practices for producing and handling the new energy crops at the local, regional and national scale
Develop studies on plant, soil and water interactions	Implement improved techniques for soil-water storage and water use by the plants
Establish optimal agronomic practices for sustainable production, including existing waste removal	Develop and test agricultural practices to enhance crop production, improve consistency and reduce stress susceptibility
Develop studies on the life cycle and energy balance of biomass feedstock to reduce the energy consumption of the energy farming systems	Develop improved production systems with less-intensive energy demands
Identify the most suitable soils and regions to grow energy-intensive crops	Establish agro-ecological zoning for energetic crops in the new agricultural expansion areas
Develop harvesting and processing systems to improve the woody removal activities and the use of coproducts and wastes	Establish forestry parameters that maximize sustainable forest biomass production
Develop technologies to enable the establishment and management of energy forests in areas unsuitable for agriculture or degraded areas; identify requirements for establishing agroforestry arrangements on the small scale	Validate forestry-production systems on marginal lands, abandoned farmlands or soil-polluted lands

3.1 Poplar (*Populus* ssp.)

Under a European-Mediterranean environment, species from *Populus* are economically feasible to be utilized as bioenergy crops, since they have all the necessary viability requisites:

- Easiness for crop establishment (vegetative propagating from stem cuttings, low cost production and high percentage of rooting success)
- High degree of genetic improvement offered (the genome of *Populus* is already sequenced)
- Fast growth and high sustainable yields
- Vigorous re-growth after coppicing and harvesting operations
- Positive energy balances
- High tolerance of competition

Fernández et al. (2009) estimated the yield in Spain from poplar based on data for potential evapotranspiration, given an average production ranging from 10.1 to 14.4 t ha^{-1} yr^{-1}. Also, studies have shown that biomass from poplar short-rotation plantations has a positive energy balance and a more beneficial effect on the environment than alternative biomass sources (Sevigne et al. 2011). However, a possible drawback of SRPs on a large scale is the requirement for irrigation under Mediterranean climatic conditions, as well as the water footprint in other European Union areas (Gerbens et al. 2009).

More recently, Pérez et al. (2013) have studied the biomass production potential for the Spanish Iberian Peninsula using the "I-214" clone of *Populus* spp. under several management regimes and land-availability scenarios. Empirical models were fitted to the data from a network of 144 plots located at 12 sites in Mediterranean climatic regions; specifically, four models were developed considering the average maximum temperature of the hottest month, length of drought, intensity of drought and soil pH. Predictions were made for the irrigated agricultural land, and the energy production capacity was evaluated taking into account the alternatives for transforming the biomass of poplar short-rotation crop: heat, bioethanol and electricity. According to the findings, the mean poplar productivity ranged between 15.3 and 10.9 t ha^{-1} yr^{-1} for a standard management scenario and the poorly irrigated and weeded management scenario, respectively. Thus, poplar short-rotation plantations could significantly contribute towards providing stability to the biomass for energy market, as well as helping to achieve greater energy self-sufficiency in the Mediterranean climate areas of Spain. It would also prove useful to other entities involved in the biomass industry, facilitating the identification of the most suitable areas for establishing biomass consumption industries.

Additionally, poplar wood is quite adequate for combustion, with low emissions and tendency to sinter, and as a consequence equipment has low upkeep costs and ultimately high energy efficiency, ranging between 155 and 167 GJ ha^{-1} (Scholz and Ellerbrock 2002).

On average, poplar trees in a coppice culture under temperate European conditions have dry-mass yields of 10.0–15.0 t ha^{-1} y^{-1} (Labrecque and Teodorescu 20035). *Populus* spp. has the advantages of a being thoroughly studied species in terms of ecophysiology and productivity and has the ability to protect the soil against erosion and control nitrate leaching (Isebrands and Karnosky 2001). Some studies have developed the use of poplar for phytoremediation of contaminated soils by short-rotation plantation cultures (Ruttens et al. 2011). Also, many studies concern cultivation, production and technological aspects of short-rotation plantations with poplar, and it is widely known that the success of these systems depends on the establishment and the first-year performance of stands (Otto et al. 2010).

Poplar is a light-demanding species, and weed control in short-rotation plantations is crucial during the establishment period. In this context, Broeckx et al. (2012) have conducted a large-scale experiment in Belgium with a short-rotation plantation system, selecting 12 *Populus* genotypes, and characteristics of production have been assessed during the first 2 years, reaching a volume index ranging from 1.00 (±0.68) to 1.93 (±0.97) dm^3 in the first and from 2.75 (±1.70) to 11.91 (±0.63) dm^3 in the second season. Average growth rates were 247 cm of tree height and 445 cm of trunk diameter and 25.1 mm and 40.7 mm after the first and second growing season, respectively. These authors found a high potential of short-rotation plantations with poplar on agricultural land for bio-energy purposes.

On the other hand, Deckmyn et al. (2004) compared the benefits for C sequestration of afforestation with a multifunctional oak-beech forest vs. poplar short-rotation plantations by running Stand to Ecosystem Carbon and Evapotranspiration Simulator (SECRETS) and Graz Oak Ridge Carbon Accounting Model (GORCAM). These authors calculated the net primary production of oak-beech forest of 2.5 t C ha^{-1} yr^{-1} after 150 years, compared to 6.2 t C ha^{-1} yr^{-1} for a poplar short-rotation plantation. When taking into account the energy substitution, coppice cultures reduce emissions with 24.2–29.3 t CO_2 ha^{-1} yr^{-1} while the oak forests reduce only 6.2–7.1 t CO_2 ha^{-1} yr^{-1}. Recently in this context, Fiala and Bacenetti (2012) have evaluated the economic, energy and environmental impact in short-rotation plantations harvesting operations in two different poplar plantation systems. The economic cost, energy input and greenhouse gas emissions depended on the yield, the annual use of the machines and the scheduling of operations. These authors have concluded that the best systems are achieved when harvest and transport are carried out in an area larger than 400 ha, with an effective plantation design, a proper-sized transport system and without mechanical failures. In such situations, the productivity of the harvest transport system can reach 65 $t_{wb}h^{-1}$ (wet basis), while the economic cost, the energy input and greenhouse gas emissions reach, respectively, 15 MJ per t_{DM}, 212 MJ per t_{DM} and 16 kg CO_2 eq. per t_{DM}.

On the other hand, especially for European Union-Mediterranean countries, it is essential to develop a better understanding of water use efficiency for poplar, as the short-rotation plantation is expected to be extended intensively, making it necessary to perform spatial predictions and upscaling of yield for optimizing environmental and economic profits. Figure 6 shows the field performance for assessing the poplar biomass yield in Granada (SE Spain). In this line, Tallis et al. (2012) have recently promoted a process-based model for poplar and willow short-rotation plantations (ForestGrowth-SRC) and exposed its capacity to predict yield and water use efficiency. This model has predicted an annual biomass yield for poplar of 1.46 oven-dried tonnes (odt) ha^{-1} $year^{-1}$ and higher water use efficiency for poplar than for willow (9.5 and 5.5 g kg^{-1}, respectively). These authors confirm that the model can be used to forecast present and future short-rotation plantation yields at a regional scale. Table 5 lists the fixed wood-yield biomass under short-rotation plantation systems in different European Union producer countries.

In this same context of becoming environmentally efficient, it is important to take into account that short-rotation plantations need fertilizer to achieve high biomass production. The use of wastewater as nutrient sources has been investigated in several countries from the early stages of short-rotation plantation development. Diverse studies have shown the potential of using wastewater for increasing net benefits of these systems by decreasing fertilization costs and increasing biomass production (Börjesson and Berndes 2006). Latterly, Dimitriou and Rosenqvist (2011) have examined the implications of an improved economy of short-rotation plantations by using wastewater and sewage sludge, compared to conventional practices, concluding that the gross profit margin increases when sewage sludge and wastewaters are applied to poplar SRP (39 and 199€GJ^{-1}). They also conclude that if all available sludge and wastewater were applied to SRP, they could be grown in large agricultural areas in European Union countries.

In relation to harvest technologies apart from moisture content, the particle size distribution of chips is the other important characteristic for biomass quality. Pari et al. (2013) have evaluated the effects of the harvesting method on the quality of wood chips in poplar short-rotation plantations in Italy. Single-pass and double-pass harvesting were compared. Standing stems and cut windrowed stems were harvested using two modified foragers alternately equipped with a drum or a disc chipper, allowing a further comparison of different chipping devices. These authors have demonstrated that the harvest mode and chipping device (drum or disc) significantly affect the particle size distribution. In fact, the harvesting cost is estimated to be higher than 50 % of the total produced from wood plantations (Moiseyev and Ince 2000). Compared with willow, poplar is lighter and more breakable, and poplar stools generate fewer but larger sprouts when coppiced (Tharakan et al. 2003), this factor having a major impact on harvest performance. To test this, Spinelli et al. (2009) conducted a study to model the performance of modified foragers on poplar plantations. The average yield of the fields harvested during the trials was about 23 gt ha^{-1} yr^{-1},

Fig. 6 Poplar plantation under a 2-year coppicing cycle (**a**), tree growth measurement (**b**), field performance for different poplar clones (**c**) and drip irrigation system for poplar short-rotation plantations (**d**) in Granada (SE Spain)

Table 5 Woody biomass yield from different species in EU countries

Country	Species	Yield (t_{DM}ha^{-1})	Production costs (€GJ^{-1})	Rotation (years)	Calculation period (years)	Reference
Czech Republic	*Populus*	10.0	3.3	3	21	Havlicková and Weger (2009)
Italy	*Populus*	16.7–33.7	–	2	10	Fiala and Bacenetti (2012)
Italy	*Populus*	10.0	4.1–4.9	2	8	Manzone et al. (2009)
Italy	*Populus*	13.0–10.0	–	3–2	10	Di Matteo et al. (2012)
Spain	*Populus*	13.5	0.8–0.85	5	16	Gasol et al. (2009)
Spain	*Eucalyptus*	10.0–15.0	–	–	8–10	Iriarte (2008)
Spain	*Eucalyptus*	19.0–20.5	–	3–2	10–15	Jiménez et al. (2013a)
Portugal	*Eucalyptus*	20.0	–	–	8–10	Sebastián et al. (2010)
Germany	*Paulownia*	12.7	–	–	–	Maier and Vetter (2004)
Spain	*Paulownia*	35.0–45.0	–	3	21	Gexbioma (2013)
Spain	*Paulownia*	2.6–6.0	–	3–5	–	Martínez et al. (2010)
Spain	*Paulownia*	7.0–14.0	–	2–10	–	Durán et al. (2014)
Germany	*Robinia*	3.0–10.0	–	3–6	–	Grünewald et al. (2009)
Italy	*Robinia*	1.96	–	1–2	–	Kellezi et al. (2012)
Hungary	*Robinia*	6.7–9.7	–	5–7	–	Rédei et al. (2011)
Germany	*Robinia*	3.0–10.0	–	–	–	Quinkenstein et al. (2012)
Ireland	*Salix*	8.8	1.7–2.6	3	23	Styles et al. (2008)
Ireland	*Salix*	12.0	2.8	3	22	Rosentvist and Dawson (2005)
Poland	*Salix*	9.0	1.4	3	22	Ericsson et al. (2006)
Sweden	*Salix*	9.0	6.8	3	20	Rosenqvist et al. (2013)
Sweden	*Salix*	4.15		5.73	10	Mola (2011)
Germany	*Salix*	8.2	–	–	–	Maier and Vetter (2004)
EU	*Salix*	9.0	4–5	3	22	Ericsson et al. (2006)

and machine productivity ranged from 9 to 70 green tonnes per scheduled machine hour (gt SMH^{-1}), with an average value of 35 gt SMH^{-1}. They also produced a model to estimate harvesting performance and cost, demonstrating that the harvesting cost can be lower than 15€gt^{-1} (2€GJ^{-1}) level, only if field stocking is higher than 40 gt ha^{-1}.

In Spain, in spite of the great interest shown by several socio-economic actors, as well as the feasibility (Gasol et al. 2009), the production chain is still not well defined. The energy companies are demanding more quantities of biomass in the local market and, at the same time, in rural areas, and farmers do need guarantees that their production can reach reasonable prices.

3.2 Eucalyptus (*Eucalyptus* sp.)

Eucalyptus has been used in forestation in Europe since the early nineteenth century because of its high productivity and plasticity. The current total area occupied by eucalyptus plantations in Southern Europe is approximately 14,000 km^2, with *Eucalyptus globulus* being the most common species but with an increasing proportion of *Eucalyptus nitens*, which is grown successfully as a frost-tolerant species. The management objective of these plantations in Southern Europe is currently the production of wood pulp or fibreboard, although logging residues and the bark derived from the harvesting operations are increasingly used as biofuel to produce thermal energy and electricity.

According to Johnson et al. (2007), eucalyptus species adapt well to energy production because of the higher yield and lower water and nutrient requirements than for poplars and willows. Eucalyptus plantations in Southern Europe established at initial densities of 1000 to 2400 trunks per hectare can therefore supply the bioenergy industry as the main plantation objective or through the use of logging debris for energy purposes. Figure 7 shows the field performance for eucalyptus short-rotation plantations in Granada (SE Spain). Eucalyptus plantations in Spain are managed by intensive regimes, including mechanical soil preparation, fertilization at establishment and planting of 1000–1500 containerized seedlings per hectare. Brush weeding is applied frequently before canopy closure, and clear cutting is carried out at 10–12 years. Spanish eucalyptus pulp factories are beginning to use the timber, although the basic density of the wood is lower than that of *E. globulus*, as pointed out by Pérez et al. (2006). Recently, Jiménez et al. (2013a) reported the biomass yield

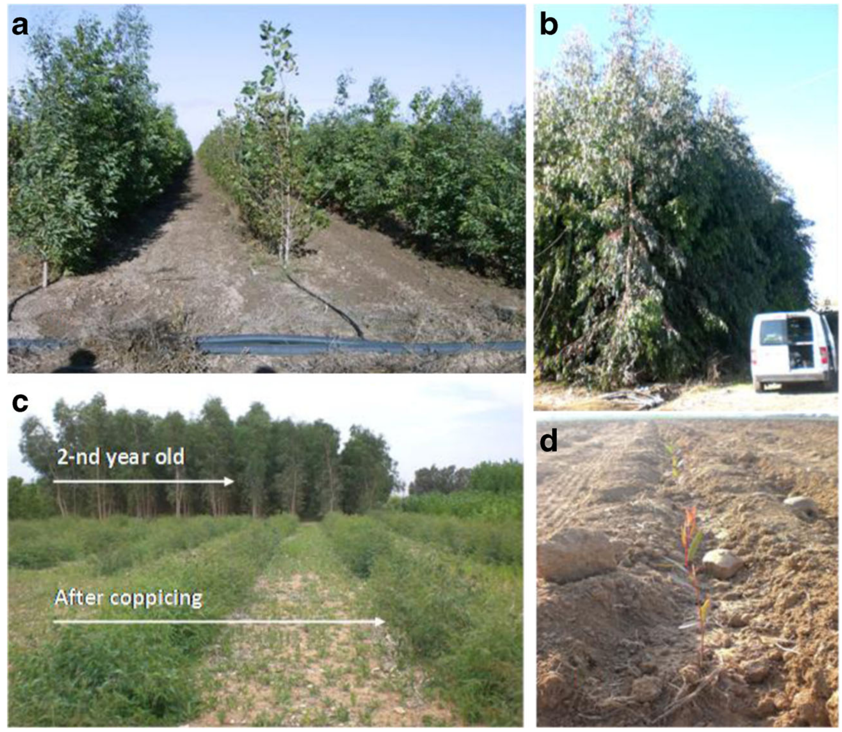


Fig. 7 Drip irrigation system for eucalyptus short-rotation plantations (**a**), tree height of a 3-year-old eucalyptus plantation (**b**), plot under a 2-year coppicing cycle management (**c**) and eucalyptus stand for field performance (**d**) in Granada (SE Spain)

potential under short-rotation plantation management for the Mediterranean Spanish area for *Eucalyptus camaldulensis* and *Eucalyptus dunnii* of 19.0 and 20.5 $t_{DM}ha^{-1}$ after 3- and 2-year coppicing cycles, respectively (Table 5).

Studies concerning its environmental viability are currently being conducted. For example, Gabriele et al. (2013) have evaluated the environmental impact of delivering 1 GJ of heat from eucalyptus short-rotation plantations using life cycle assessment (LCA). Compared to equivalent fossil fuel production chains, all eucalyptus scenarios offered savings of fossil energy and greenhouse gas emissions of 80–90 % and had a generally lower impact, as pointed out by González et al. (2012a) on assessing the environmental effects of eucalyptus-based ethanol production in comparison to conventional gasoline.

Fuel properties are directly related to the age and height of eucalyptus, according to Kumar et al. (2011), who investigated these parameters in relation to fuel properties. A strong increase in the calorific value with the age of tree (2–6 years) was found with a significant variation, and the fuel properties of younger tress were compared with those of mature trees (20 years). In general, the fuel properties of mature trees were better than those of younger trees.

Pérez et al. (2011) have conducted a study to develop a tool for estimating biomass and bioenergy production and carbon sequestration in *E. globulus* and *E. nitens* planted at the observed range of initial stocking densities in Southern Europe, as well as to propose two crop management regimes for both species. These authors found a higher yield in *E. nitens* than in *E. globulus* for all variables because of faster diameter increment at similar densities. The total yield in terms of biomass was from 13.9 to 14.6 t ha^{-1} yr^{-1} for *E. globulus* and between 20.4 and 21.5 t ha^{-1} yr^{-1} for *E. nitens*. Energy in aboveground biomass ranged between 233 and 245 GJ ha^{-1} yr^{-1} for *E. globulus* and 345 and 364 GJ ha^{-1} yr^{-1} for *E. nitens*. In this line, Sochacki et al. (2007) developed equations that relate stem diameter over bark at 10 cm (D_{10}) and tree height (ht) to total tree biomass, leaves, stems and roots by combining data from different planting densities (500, 1000, 2000 and 4000 stems ha^{-1}) and landscape positions (upper slope, mid-slope and lower slope). Mean oven-dried yields of the three species, in the high-planting-density treatment, did not significantly differ, ranging from 12.0 to 14.0 t ha^{-1}(3 years)$^{-1}$. Biomass increased with higher planting density, and productivity also varied with slope position. In this sense, *E. globulus* and *E. occidentalis* had the highest yield in lower landscape positions with initial planting densities of 4000 stems ha^{-1}, with 16.6 and 22.2 t ha^{-1}(3 years)$^{-1}$ of total biomass produced, respectively. These authors confirmed that biomass productivity can be optimized by using high initial planting densities and recognizing the interaction of different species with site hydrology.

Additionally, studies have examined litter decomposition and nutrient cycling, since much of the concern about the sustainability of short-rotation plantations focuses on the matter of the considerable consumption of soil nutrients due to whole-tree harvesting and short harvest cycles (Ericsson

1994). Guo et al. (2006) studied litter fall and nutrient return during the first 3 years of rotation of three *Eucalyptus* short-rotation forest species (*E. botryoides*, *E. globulus* and *E. ovata*) irrigated with meatworks effluent compared with non-irrigated. Annual litter fall reached 13.4 odt ha^{-1} yr^{-1}, with macronutrient returns of up to 159 kg N ha^{-1} yr^{-1}, 9 kg P ha^{-1} yr^{-1} and 28 kg K ha^{-1} yr^{-1}. Irrigation caused higher amounts of litter fall and higher return of some nutrients. The highest litter fall and nutrient return rates were found for *E. globulus*. During the 3-year period, litter represented 20 % of the aboveground biomass and, via the litter fall, up to 24 % of the total N uptake was returned to the soil surface.

3.3 Paulownia (*Paulownia* sp.)

The genus *Paulownia* is attracting greater attention as bioenergy crop and considerable interest as an industrial raw material (Jiménez et al. 2005; Kumarmangalam et al. 2013). The genus is composed of nine species, most having very fast growth, being possible to harvest only 15 years after planting to achieve high added value products (Kalaycioglu et al. 2005).

Durán et al. (2014) have evaluated the potential biomass production of *Paulownia elongate* and *Paulownia fortunei* with two of their clones (Cotevisa 2 and Suntzu 11) in six different locations in Andalusia (S Spain) (Fig. 8). According to their findings, Cotevisa 2 was more productive (1.8-fold higher) in terms of biomass than Suntzu 11. Also, a significantly higher woody biomass yield was found for both clones, ranging between 7.2 and 14.0 $t_{DM}\,ha^{-1}$ in Villanueva del Río y Minas (Sevilla province, Spain). By contrast, significantly lower paulownia biomass production was found at Palma del Río (Córdoba province, Spain), registering between 1.7 and 2.3 $t_{DM}\,ha^{-1}$ (Table 5). Thus, the introduction of Paulownia in a Mediterranean climate is also feasible, although data are still scant and further research related to management, water efficiency and carbon sequestering is needed.

In addition, López et al. (2012) have analysed paulownia as a raw material for solid biofuel production, reporting lower ash content (8.9 g kg^{-1}) and higher cellulose content (440 g kg^{-1}) than other woody energy crops. Also, a low content in S and N was observed in comparison with poplar or willow, with a gross heating value of 20.3 MJ kg^{-1}, this being somewhat higher than for hardwood, slightly higher than for *Pinus pinaster* and softwood and much higher than those for residues of food plants and agricultural crops. In this context, according to Jiménez et al. (2013b) in southern Spain, a higher calorific value has been achieved using paulownia (18.6 MJ kg^{-1}) and poplar (18.5 MJ kg^{-1}); biomass with lower chlorine content in relation to herbaceous biomass and paulownia biomass also produced lower ash content with respect to poplar (1.45 vs. 2.50 %, respectively).

In China, paulownia is being used in some types of agroforestry systems (Lu et al. 2004), providing agricultural benefits, which is important in maintaining the ecological system and its sustainability. In addition, paulownia intercropping systems have been studied by Yin and He (1997), this study being related to crop yield, rotation period, tree densities and light and heat distribution. In this context, the economic and energy features in developing a paulownia intercropping system have been reported by Jianbo (2006). This author reported an energy output to input ratio of paulownia intercropping systems of 1.39 (compared with non-paulownia intercropping system or conventional systems of 1.27). In economic terms,

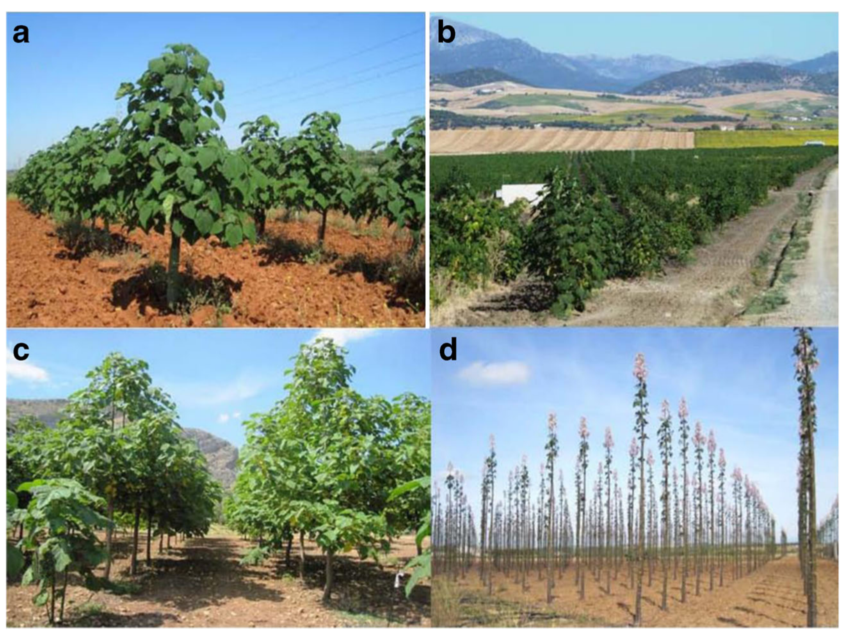


Fig. 8 Paulownia plantation under a 2-year coppicing cycle (**a**), large paulownia plantation (**b**), a 2-year old paulownia short-rotation plantation (**c**) and field performance for wood production (**d**) in Andalusia (S Spain)

the output to input ratio of paulownia was 2.45 (compared with 2.25 from the non-paulownia intercropping system). Consequently, the intercropping system has higher energy efficiency and also provides better financial returns.

3.4 Willow (*Salix* sp.)

The capacity of vigorous growth after coppicing and the extensive root system are important attributes of willow, making it ideal for reducing nutrients entering streams (Volk et al. 2006). Willow is also ideal for energy purposes due to its ease of vegetative propagation by using cuttings, rapid growth and high yield on short-rotation systems especially in northern European countries (Table 5).

However, the cultivated willow with a short-rotation plantation area in Sweden has remained almost stable or has slightly decreased during recent years (Fig. 9a, b). In this context, the bioenergy produced in the planted SRP areas in Sweden has not reached expectations because of the lower than predicted biomass production and the termination of some willow short-rotation plantations. Dimitriou et al. (2011), as stated before, analysed the reasons for these low yields by examining the results of a survey where 175 willow SRP growers participated. Lower biomass yields are due to (i) the low input in management activities, (ii) the choice of land for the willow SRP (iii) and the level of personal involvement of the growers.

Willow short-rotation plantation systems are usually established by inserting cuttings vertically into the soil, but their capacity to reproduce vegetatively has also been demonstrated by planting cuttings horizontally. In Finland, Cao et al. (2012) have conducted an experiment to compare the soil-solution chemistry and the growth of stem and roots of willow cuttings (*Salix schwerinii*) with vertical or horizontal planting orientation and using two planting densities (7500 and 22,500 cuttings ha^{-1}). They have found similar stem yield in the horizontally planted cuttings (4.08 $t_{DM} ha^{-1}$) as in the vertically planted ones (4.86 $t_{DM} ha^{-1}$). The stem biomass doubled at the higher planting density (6.34 $t_{DM} ha^{-1}$) compared to the lower one (3.36 $t_{DM} ha^{-1}$). Planting orientation or density had no effect on the root biomass or production.

The short-rotation plantations of willow have also been studied from an economic perspective. Rosenqvist and Dawson (2005) reviewed the economics of willow as an energy crop in Northern Ireland, comparing gross margins for willow production with equivalent outputs from grain production, lowland sheep and suckler cow production. The model used indicated a gross margin of £45 ha^{-1} yr^{-1} for a 12-$t_{DM} ha^{-1}$ annual coppice crop. This was equivalent to a 7-t winter wheat crop at £70 t^{-1} and compared favourably with both lowland sheep and suckler cows. Thomas et al. (2010) also studied the establishment costs of short-rotation plantations of willow in mid-Wales, comparing two mechanical planting systems, the traditional Turton Step planter and a prototype layflat planter. Establishment factors of stem density, survival rates and estimated biomass yields of a range of willow varieties during the first 3 years of growth were greater for the layflat-planted willows than for step-planted ones. At the first harvest (four growing seasons), layflat-planted willows gave mean yields of 6.22 odt ha^{-1} yr^{-1}, while 3 years into the second rotation, estimated yields ranged from 1.99 to 12.34 odt ha^{-1} yr^{-1} (mean of 8.14 odt ha^{-1} yr^{-1}). Additionally, layflat planting showed lower planting costs by 48 %, and yields achieved were equivalent to those of traditionally planted short-rotation plantations.

MacCracken et al. (2011) also studied the effects on yield of genotype mixtures comprising 5, 10, 15 and 20 components at 3 planting densities (10,000, 15,000 and 20,000 cutting ha^{-1}). The total yield from mixture plots proved higher than the mean of the components in mono-plots. However, there was no clear advantage in augmenting the number of components from 10 to 15 or 20 although host diversity is considered to be a major contributor to the effectiveness of a mixture both in disease reduction and yield enhancement. Thus, they concluded that the use of *Salix* spp. mixtures is highly beneficial and that mixtures increase the sustainability of a willow SRP system.

Fig. 9 Harvest operation in willow plantation in Skane, Sweden (**a**), and fresh willow bales at Tågra Farm in Skane, Sweden (**b**)

Biomass SRP willow production has also been studied by comparing different soil types. Sevel et al. (2012) conducted an experiment including four commercial clones of willow grown on two different soil types in northern Denmark. The average annual biomass production for studied clones was from 5.2 to 8.8 odt ha^{-1} yr^{-1} with a significant effect of soil type and clone used.

Abrahamson et al. (2002) reviewed 15 years of research on willow biomass production in the USA and found the benefits in reducing SO_2 and NO_x emissions when using willow biomass for co-firing with coal. In Europe, there are several studies with willow on marginal lands (Vande et al. 2007) that emphasized the potential of these lands to support willow short-rotation plantations, even on sandy soils with low fertility. Therefore, planting SRP systems with willow in marginal areas does not compromise food production, and demands for energy crop supplies can be met almost entirely in these lands. Recently, Amichev et al. (2012) conducted a study to evaluate the potential biomass yield of SRP willow and C implications. After 44 years, the potential average cumulative harvested biomass C was 244 t C ha^{-1} (5.5 t C ha^{-1} yr^{-1}). As a consequence, they concluded that short-rotation bioenergy crops offer one way to reduce the rate of CO_2 accumulation in the earth's atmosphere.

Biodiversity is also another factor to take into account when transforming land into short-rotation plantations of willow since it represents an important land use change in agro-environments. Few studies, however, have examined the effect of short-rotation bioenergy plantations on biodiversity. Although, Rowe et al. (2011) have investigated how the abundance and diversity of ground flora and winged invertebrates varied between mature SRP willow and two alternative land use options (arable crops and set-aside land). They found that taxonomic composition varies markedly, with Hymenoptera and large Hemiptera being more abundant in willow short-rotation plantations than in arable or set-aside land, and despite that plant species richness was greater in set-aside land, willow SRP supports a different plant community from the other land uses. Therefore, a mixed farming system incorporating willow SRP can benefit native farm-scale biodiversity, and the predominance of perennial species can provide refuge and food for invertebrates.

In addition, Jones et al. (2012) have compared the combustion properties of raw and torrefied SRP willow with those of typical bituminous power station coals. Results show that the N partitioning for both raw and torrefied biomass favours N release into volatiles during rapid pyrolysis. In contrast, rapid pyrolysis of the coals favours N retention in the char. The char reactivities follow the order coal char < torrefied willow char < raw willow char. The release of volatile nitrogen species during char combustion occurred at higher temperatures for the torrefied willow chars compared to the raw willow chars due to their relatively lower reactivity.

3.5 Robinia (*Robinia pseudoacacia* L.)

Another potential tree for SRPs in Europe is black locust, which originates from eastern USA, and was introduced to Europe during the seventeenth century, being spread in Europe as an ornamental tree and later for timber production. Today, large areas covered with black locust can be found in Central Europe and, especially, in the southeastern parts of Europe (Böhm et al. 2011). The causes for the popularity of this plant are diverse. Black locust has an extensive root system and is thus widely used for land protection and soil erosion control as pointed out by Zhou and Shangguan (2005). Additionally, it is a light-demanding pioneer species that prefers well aerated, light soils but tolerates a wide range of soil types. It has a vigorous resprouting capacity after cutting and high wood density, which is particularly useful for the production of woody biomass. In this sense, Böhm et al. (2011) have developed allometric equations based on tree height and shoot basal diameter to predict *Robinia* biomass yield. These authors reported that woody biomass of young black locust can be predicted acceptably based on easy field parameters such as tree height and shoot basal diameter.

Robinia has also been studied as part of mixed agroforestry systems for energy purposes. In this context, Gruenewald et al. (2007) studied two agroforestry systems in Germany (Lusatia and Helmstedt), using poplar, willow and locust with different rotation periods (3, 6 and 9 years) (Table 5). They obtained the highest yields for both sides with *Robinia*, for the three rotation periods. In the agroforestry system in Lusatia, they paid special attention to the interaction between *Robinia* trees and crops (*Medicago sativa* L.) without negative influence on the yields of this latter. Therefore, under an increasing demand scenario for woody biomass, alley cropping using black locust is a potential alternative for future land use.

In Italy, although the current SRP surface area is low compared with the main crops, there are more than 100,000 ha of agroforest species such as poplar, eucalyptus and locust, these areas having a high potential for biomass production for energy purposes (Pettenella and Masiero 2007). In this context, Gasol et al. (2010) have evaluated the economic viability of black locust as an energy crop in a low-input regime and have evaluated its competitiveness with wheat. Their results have shown that neither short-rotation plantation techniques nor biomass production can generate a positive profit that can persuade farmers to invest in biomass plantations, since wheat is a more economically viable option. Hence, the viability of biomass production in Southern Europe must be supported by incentives from the governments.

The life cycle analysis has also been applied to *Robinia* under short-rotation plantation system to assess their environmental implications. In this context, González et al. (2011)

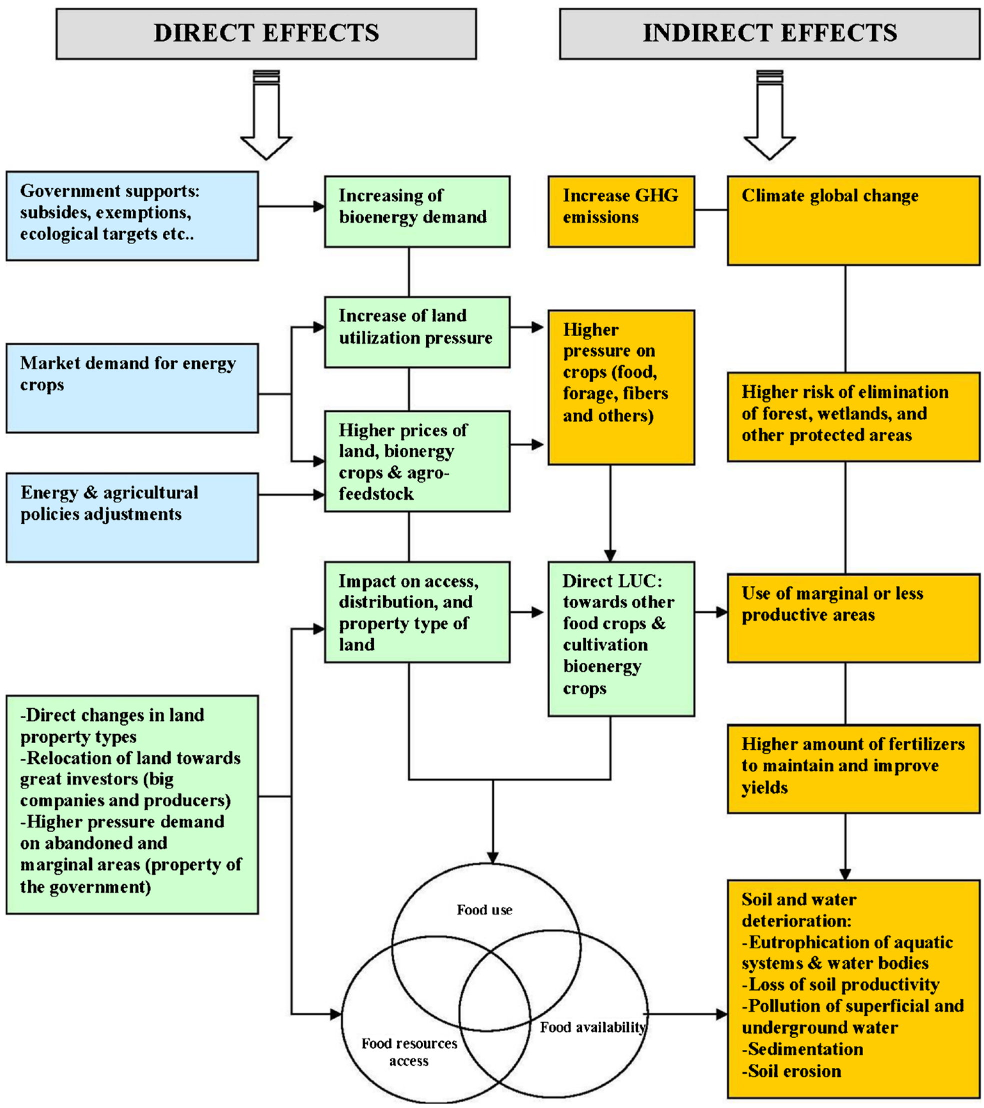
conducted this analysis for ethanol obtained from black locust, assessing the environmental profile of using ethanol mixtures E10 and E85 as transport when compared with conventional gasoline. They concluded that fuel ethanol from *Robinia* biomass can contribute to reduce global warming, acidification, eutrophication and fossil fuel consumption, mainly because of the low-use production regime of the agricultural stage. Additionally, the utilization of lignin, biogas and other solid waste as fuel to meet energy demands helps reduce environmental impact of cellulosic ethanol.

4 Environmental impact and challenges for sustainable energy farming development

Short-rotation plantations producing biomass for heat and electricity are one of the promising means to contribute to meeting the European targets to increase the amount of renewable energy and have been identified as the most energy-efficient C conversion technology to reduce greenhouse gas emissions. However, intensive culture can exert a potential impact that can complicate their development or, at least, should be taken into account. Figure 10 shows the interrelation and feedbacks in land use changes with the establishment of short-rotation plantation systems.

It is well known that trees grown with an intensive weed control give rise to higher erosion rates than no-till agricultural production; however, this problem may be controlled by planting cover crops between the tree rows, as demonstrated in cultivating rainfed-tree crops (Durán et al. 2008). Moreover, Malik et al. (2001) studied the effects of varying strip widths of four species of cover crops on the growth of sweet gum (*Liquidambar styraciflua* L.) seedlings planted as a short-rotation bioenergy woody crop. This study reported that cover crops of lespedeza, tall fescue, crimson clover and

Fig. 10 Relationships among woody biomass production development, direct and indirect land use changes



ryegrass reduced the biomass of sweet gum by approximately 41, 37, 27 and 15 %, respectively, compared to the control. Furthermore, studies have investigated the influence of biomass energy production on biodiversity. Pedroli et al. (2013) discussed the compatibility of the objectives of the 2020 horizon for renewable energy with the conservation of biodiversity. They concluded that the increasing demand for biomass for energy production will transform valuable landscapes into productive land, and will intensify other productive areas, with negative effects on biodiversity. However, in some areas, biomass will promote opportunities for biodiversity, since perennial crops may lead to increased biodiversity. Consequently, the effects of cropping of biomass and/or elimination of biomass on biodiversity depend on specific regional circumstances, the type of land and land use changes, and the crop management.

Nitrate leaching and groundwater recharge has also been investigated recently for willow and poplar SRP (Schmidt and Lamersdorf 2012). The found important increases in nitrate concentrations in poplar site during winter and spring (16.6± 1.6 mg NO_3-N L^{-1}, with losses of 1.36±1.1 kg ha^{-1}; leaching losses from a nearby willow plantation were 14.3± 6.6 kg NO_3-N ha^{-1} during spring which decreased to 2.0± 1.5 kg NO_3-N ha^{-1} during the subsequent period). They concluded that a well-managed SRP can prevent nitrate leaching in sensitive areas, and impacts on groundwater recharge can be ameliorated by management options.

Also, changes in organic carbon and trace elements have been studied in SRP. Dimitriou et al. (2012) evaluated the changes in the concentration of organic carbon and trace elements, in a soil cultivated with a 14-year willow and compared with the adjacent arable soils. Carbon was higher in SRP than in the surroundings (9 % in topsoil and 27 % in subsoil).

Also, SRP could provide multiple environmental advantages, mainly in areas with low landscape heterogeneity (Busch 2012). This author carried an evaluation of the environmental effects of the SRP based on the preferences and planning as allocation criteria. There is a clear preference according to physiographical conditions for mini-SRP, which is also supported by a smaller decline of annual deep percolation compared to maxi-SRP. The preferences for installing SRP could change with increasing incentives and subsidies.

On the other hand, discussion about the sustainability of energy crops has usually focused on the analysis of land use changes and energy balances. Even the Directive of Renewable Energy requires the analysis of the greenhouse gas emissions and impact on biodiversity where they are cultivated. However, there was no requirement on energy balances or water consumption (Sevigne et al. 2011). In this sense, there are some studies related to the water footprint analysis of biofuels (Stone et al. 2010; Iriarte et al. 2010). However, studies related to the consumption of water resources in areas with significant water shortages, such as the southeastern Spain, are scarce. In this context, Sevigne et al. (2011) evaluated the relation between water, energy and CO_2 emissions for a *Populus* field trial in Spain to evaluate the feasibility of its establishment as a large-scale crop, highlighting the positive energy balance and environmental improvement with respect to other energies, such as natural gas. The water consumption required to avoid a kilogramme of CO_2 is 4.6 m^3 and per unit of energy obtained is 45 m^3 GJ^{-1}. They also concluded that the cultivation of *Populus* spp. should be restricted to areas with no water shortage. Also, these authors suggest the use of *Populus* as a complement for power plants together with the use of forest residues, agricultural residues, etc. and the reuse of urban or industrial water for irrigation.

Also in Spain, Butnar et al. (2010) evaluated poplar and Ethiopian mustard for power generation. They calculated different scenarios of electricity production from biomass in power plants of different capacity (10, 25 or 50 MW), different transport scenarios and different productivity rates for biomass production. They reported that Ethiopian mustard is more environmentally damaging than poplar when used for electricity production. Compared to electricity from natural gas or the Spanish electricity mix, the electricity obtained from biomass is more damaging in three of six impact categories they evaluated (acidification, human toxicity and photochemical oxidation). Also, better environmental profiles were found for 10 or 25-MW power plants. In addition, in order to guarantee a good environmental profile of the electricity from biomass, the transport distance from the field to the power plant has to be as low as possible. Moreover, since the most harmful step in the cultivation of biomass is the use of fertilizers, a possible measure to reduce these effects is to replace mineral fertilizers with natural fertilizers such as livestock manure, etc.

In this context, according to Dinica (2009), from a logistical perspective, improvements are needed in resource collection, transport, storage and processing. These affect both the size and the reliability of the resource market, as all stages influence the energy quality of resources in time, exerting an effect on the final production costs of biomass power. Also, cultural factors affect mainly the size of the available market. In this sense, many potential suppliers of biomass do not consider themselves as such. This is a fact for farmers, industrial companies, public agencies managing public lands and other private actors (IDAE 2005). There is strong resistance of farmers to change to a completely new type of cultivation, such as energy crops (Dinica 2009). Even farmers who already have biomass wastes as by-products have been reluctant to seek or respond to contacts for biomass supply to power producers.

In terms of biofuel environmental analysis, González et al. (2012b), by using the life cycle assessment, analysed the environmental impact of the production and use of ethanol from three energy wood crops in a Spanish context. Ethanol from black locust was the option with the lowest impact and the best characteristics, compared to eucalyptus and poplar biofuels. Also, concerning the production stage of ethanol, black locust has the lowest environmental impact due to the low levels of agricultural inputs during its cultivation. Poplar cultivation has higher impact from fertilizer application and the eucalyptus due to the use of heavy machinery during harvesting.

According to Junginger et al. (2010), the primary obstacles for solid biomass trade in the European Union are the following:

1. The general scarcity of raw material. At the same time, this situation may increase biomass imports from outside the European Union.
2. Logistical obstacles, such as bad roads and lack of certain harbour infrastructures. Sustainability restrictions. These were considered an obstacle by market actors in Germany, the Netherlands and the UK mainly because it is unclear whether solid biomass trade will have to meet sustainability criteria.
3. Clarity on biomass-fuel quality is generally required to increase consumer's confidence.

To save these constraints, it is crucial to establish a policy harmonization to promote public acceptance by gaining public trust, which requires an efficient policy framework and communication among stakeholders (Upreti and Horst 2004). In this way, the variety of different product standards and other national or regional regulations will be replaced by a homogeneous set of standards. A strong certification system can guarantee that biomass is produced in a sustainable way, with reporting on the sustainability of bioenergy throughout the supply chain (Heinimö and Junginger 2009).

In addition, the development of short-rotation plantation systems in Europe and Spain can contribute to rural income and employment increment. Energy crops lead to changes in agricultural labour habits and contribute positively to rural diversification. Goldemgerb (2002) recognizes the generation of jobs as one of the main benefits of biomass-producing areas. Therefore, the adoption of land for the production of energy crops should be considered a possible solution to problems such as land abandonment, rising unemployment and return of people to former agricultural activities in rural areas due to economic crisis, especially in the European-Mediterranean regions. Additionally, rural development will be promoted from bioenergy guidelines which, in accordance with the rural development policies, represent a viable alternative use for large marginal areas of agricultural and forestry land.

Consequently, the implementation of small power plants should be integrated with efficient biomass management plans that include short-rotation coppicing of raw material, forestal and agricultural residues and other type of recycled wastes. This available biomass could be used for heating in residential and commercial buildings or co-firing of biomass in existing coal-fired power plants in order to improve the environmental profile of the national electricity mix. However, the sustainability of the use of underused agricultural lands for non-food and lignocellulosic bioenergy crops is controversial and uncertain for several reasons, since the environmental impact

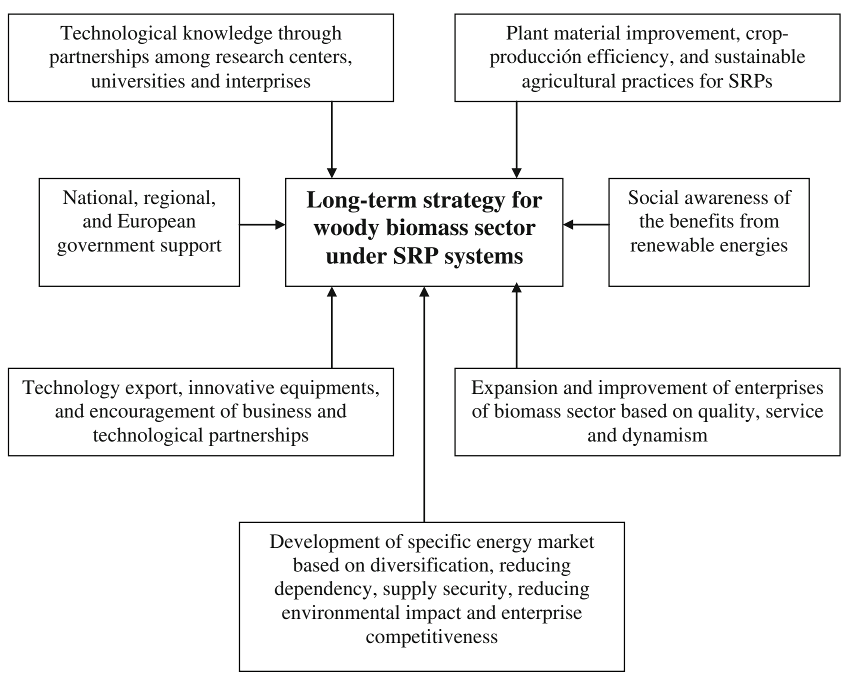


Fig. 11 Possible long-term strategy for the development of woody biomass sector from short-rotation plantations (SRPs) in Andalusia (Spain)

from the use of these lands still requires further research, as they often need significant inputs of water and nutrients to maintain productivity.

5 Conclusion

Global bioenergy resources are presumably sufficient to meet the predicted biofuel and biomass demands without competing with food production, although the land use changes will have to be carefully planned. The increase in the use of energy from renewable sources is supported by falling technology costs, by the increase and oscillating prices of fossil fuels and by continued subsidies. The bioenergy sector is innovative, and the investment in it may bring considerable strategic advantages to investor companies. However, there are still many things to know about woody energy crops, and the necessary research efforts on crop selection, development and management could delay the effective establishment of further short-rotation plantations. This could also call into question the farmers' commitment to these objectives and to the use of their lands for energy farming. Additionally, a fuller analysis of the environmental impacts is needed. Therefore, future research should concentrate mainly on key aspects such as improvement of genetic material and its adaptation to different sites to diminish the potential environmental impact, plantation design and rotation length and management operations such as weed control, fertilization and irrigation. Research related to other types of social impact is also crucial, envisaging the public participation in the process to promote farmers' interest and commitment to this new activity. Since sustainable energy farming for solid biomass production is becoming more important, especially as many biomass resources are becoming scarce, dedicated energy crop plantations may become an increasingly utilized resource.

Consequently, the short-rotation plantation systems could be considered as a promising tool for optimize and guarantee the supply of woody biomass; therefore, this production system gives the opportunity to develop this sector with high potential in Andalusia Spain. However, it is essential to implement actions that lead to continuity and stability over time, in order to foster the technological and market development (Fig. 11), thus will be crucial to address the different challenges, and develop strategies to minimize different weaknesses and take advantage of strengths and opportunities.

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