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Biomass power: Exploring the diffusion challenges in Spain

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ABSTRACT

The use of biomass resources for power generation offers numerous benefits of interest for political decision-makers: fuel security, rural and industrial development, ecological benefits. In Spain, policy instruments have been used since 1980 to stimulate biomass power generation. However, the diffusion outcome by 2007 was very disappointing: only 525 MW. This paper argues that two factors lie at the core of this: the conceptualization of biomass resources by political decision-makers in the instruments used, and the desire that policy instruments be in line with market liberalization principles. These generated a persistent economic obstacle for biomass power generation, and impeded the development of markets for the supply of biomass resources. The policy learning regarding the heterogeneity of biomass resources, and the investors' expectations on risks, profitability and resource markets was very slow among political decision-makers. The paper contributes to the understanding of diffusion outcomes by proposing to analyse diffusion by means of five indicators: types of resources, technologies, developers, motivations to invest and project sizes. Besides, the paper shows the usefulness of investigating policy instruments in terms of their risk and profitability characteristics. This enables a better understanding of the diffusion patterns and outcomes.

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1. Introduction

Spain has been one of the countries with the highest dependency on imported energy resources in the European Union. In 1973, domestic energy resources covered only 28.6% of the total energy demand. Being severely hit by the oil crises of mid 1970s, and given the absence of domestic gas resources and good quality coal, the Spanish government developed since the 1970s policies aiming at energy saving and the diversification of primary energy resources. In this framework, the use of all types of domestic energy resources became top priorities.

Biomass power was considered an important technology from the standpoint of fuel security. It was also backed-up in political declarations because of its potential to offer jobs in rural areas, supporting this way the declining agricultural sector and preventing the migration of rural population to urban areas. Besides, the job benefits would be spread throughout the country, as biomass resources have a balanced distribution across regions in Spain. Later, other motivations added to the interest in using biomass for power production: the prevention of soil erosion by means of energy crops, the reduction of fire disasters due to woody wastes in forests and organic wastes on agricultural fields, and the development of a new industrial sector for biomass power technology and services [1].

An Energy Conservation Law was put in place in 1980, aiming to stimulate the adoption of biomass power, next to other renewable energy technologies. This was revised several times, as the political commitment to renewable energy was being consolidated with environmental and climate protection arguments. However, by 2007, there were only 525 MW of power plants using biomass resources, generating just 1.1% of the total electricity production. Only 15% of the readily available biomass resources are used for electricity generation [2]. This deployment level has been assessed by all types of stakeholders in Spain as bitterly disappointing. The political target expressed in the latest Plan for the Sector of Electricity and Gas Production, of the Ministry of Economics was to achieve 3100 MW of biomass power by 2011. Since the diffusion tempo proved very slow, this target was downgraded to 1567 MW by 2010 [3].

This paper explains the deployment of biomass power in Spain, by exploring its diffusion patterns and the obstacles that influenced the limited diffusion results observed so far. It is assumed that, by studying the diffusion patterns, one can better understand how various kinds of obstacles affect diffusion. Under comparable annual capacity increases, there may lie different diffusion patterns, which enables analysts to more easily underpin the prospects of diffusion continuation. The following five indicators of diffusion patterns are proposed: types of biomass resources, types of technologies for power generation, types of developers and their motivation to invest, and project sizes.

The explanatory value of understanding the diffusion patterns of a new energy technology has been already proven in a series of studies [4–7]. They give useful signals about the level of investment interest generated among commercial agents, especially whether sufficient interest was raised among financially powerful companies. They also help understand whether investments emerge just because of favourable niche-market situations, or as mainstream commercial activities—signalling the market maturity of the new technology. The diffusion tempo can also be better understood by looking at the sizes of projects being developed and considering also the factors affecting investors' decisions on project sizes. The efficient transformation of biomass resources into power generation depends on the types of technologies used, which makes this also useful to investigate.

Understanding diffusion obstacles and the factors affecting their emergence and persistence is important in order to draw lessons for decision-makers. This paper reveals that two main types of obstacles contributed to the disappointing diffusion outcome so far: economic obstacles for power generation, and resource markets' obstacles. The generation of electricity based on renewable resources, including biomass, is still more expensive than the generation of electricity based on fossil fuels. The energy policy literature differentiates among a number of policy instruments that governments worldwide apply, to stimulate the uptake by investors of renewable electricity technologies: feed-in tariffs, tradable green certificates, investment subsidies, tax exemptions/reductions, etc. However, investors do not think and act based on policy language; rather, their language is dominated by terms such as risk and profitability [8].

In Spain, five legal frameworks have been put in place since 1980, regulating a type of economic support that policy-makers and policy academics would rather call 'feed-in tariffs'. Feed-in tariffs have been often assessed in the academic literature as 'successful instruments' because they helped the fast diffusion of some technologies in some countries [9,10]. However, in many cases of diffusion failure, the applicable instruments were also of the 'feed-in tariff' type, which is also the case for biomass power in Spain. This paper will discuss the economic obstacle of biomass power in Spain from the perspective of the risk and profitability characteristics of the policy instruments introduced to address the expensiveness problem of biomass power. Such an approach enables a much more visible connection between the characteristics of the applicable policy instruments, the diffusion patterns and the factors behind the persistence of the diffusion obstacles for more than two decades in Spain. One of the two factors responsible for the economic obstacle emerges to be also at the core of the second obstacle for biomass power diffusion: the absence of markets for the supply of biomass resources. The conceptualization of biomass resources by political decision-makers led them to underestimate the importance of a comprehensive institutional and policy framework for the development of biomass resource markets.

The paper is organized as follows. Section 2 presents an overview of the diffusion patterns of biomass power in Spain. Following this, Sections 3 and 4 examine the obstacles that influenced the observed diffusion patterns and results observed so far, and the factors underlying their persistence. Section 5 reflects on the level and aspects of policy learning among political and administrative actors, and the political will to address diffusion obstacles. Section 6 concludes the paper with a series of reflections on the lessons learned by this case study, and on the approach to diffusion analysis proposed in this paper.

Table 1
The increase in biomass power capacity and share of self-generation capacity, 1991–2000 (*Sources*: [12,13]).

Biomass power (MW)	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Installed (cumulative)	107	110	102	126	152	183	184	188	202	217
MW selling to the grid	n.a.	23.7	23.7	25.9	39.5	39.7	40.5	64.2	74.4	118
% Own consumption	n.a.	77%	77%	79%	74%	78%	78%	66%	63%	46%

Table 2
The increase in biomass power capacity, 2001–2007 (*Sources*: [14,15]).

	Year						Revised target by 2010
	2001	2002	2003	2004	2005	2007	
MW	228	361	435	450	485	525	1567

2. Diffusion patterns of biomass power in Spain

The diffusion tempo of biomass power has been very slow, as shown in Tables 1 and 2. Up to 1997, most electricity output of biomass plants was used for the consumption needs of project owners; only around one-quarter of the total installed capacity was sold to grid companies. Commercial projects have started to dominate the investment picture only after 2000 [11].

2.1. Biomass resources and technologies

Biomass is a heterogeneous resource; its characteristics need to be understood before trying to analyse the diffusion of biomass power. The complexity of understanding biomass power is compounded by the fact that most resource types can be used as fuels for more types of electricity generation technologies. Two broad categories of biomass resources can be technically differentiated, in terms of their quality, or energy content: primary resources and secondary resources. This paper discusses the diffusion of biomass power plants using both categories of resources in Spain; however, the use of residential wastes – as sources of organic matter – is not included in the analysis.

Secondary biomass resources are constituted by organic wastes from various industrial or agricultural applications of material containing organic matter; they can be, for example, generated by: the paper and furniture industries, the food and drink industries, farming companies – generating animal manure that can be transformed in biogas, sewage treatment stations and solid wastes disposal sites – generating landfill gas. These resources are called 'secondary' because their organic content had already been harnessed once, in various non-energy applications; but they still have a meaningful residual organic content that can be used for energy applications.

Primary biomass resources are considered to be forest wastes, agricultural wastes, and any other types of industrial organic wastes that were not used in any way previously (never exposed to chemical or thermal treatment); they are also sometimes referred to as 'clean resources'. Another type of primary resources is formed by dedicated energy crops, constituted by plants or trees grown for the purpose of harnessing their energy content. Many companies and public actors in Spain consider biomass power plants using primary resources as 'innovative energy systems'. Economically, primary resources are more expensive than secondary resources; but there are large differences in the costs of particular resource types within each of these two broad categories.

Four technological principles can be used for the conversion of biomass to electricity, as shown in the first column of Table 3. Direct combustion and anaerobic fermentation are conventional, technically mature technologies. They are both dominant technologies in Spain, typically using as input secondary biomass resources, as column 1 of Table 3 indicates. Of the 73 projects developed up to 2002, 57 projects use secondary resources as fuel; they account together for 74% of the total capacity installed by then [16]. Many projects use landfill gas, as this is the most inexpensive resource. However, the remaining potential landfill gas is considered very limited due to the European Union legislative limitations on the organic content of solid wastes deposited in landfills. Only 17 projects that started operating before 2002, use primary resources (agricultural or forestry wastes); most of them use these resources in direct combustion plants [16].

Gasification and pyrolysis are more recent technological designs. In Spain, only few small-size demonstration projects using gasification can be signalled so far. Most of them are owned by energy companies, large technology corporations and the national energy agency IDAE (Institute for Energy Saving and Diversification). Pyrolysis, assuming the transformation of primary biomass resources in bio-oil for electricity generation, has not been so far a priority for the industrial corporations and energy companies in Spain [17]. This is because the political support and financial incentives for the use of bio-oil in the transportation sector remains more substantial than the support for biomass electricity. Table 3 shows the extent of investment activity using various combinations of biomass resources and electricity technologies.

2.2. Project sizes

The size of projects constitutes an important indicator for the diffusion of a new technology: when projects are predominantly small size, the rate of installed capacity increase is likely to be also small, unless very many companies invest. Besides, this may be an indicator for obstacles to diffusion that need to be investigated. This is especially the case for technologies that have large economies of scale, meaning that the production costs per kWh start to decline only after the project size overpasses a certain threshold. Such is the case with biomass power for which production costs are lower for plants smaller than 1 MW or larger than 25 MW/30 MW [12]. When the observed project sizes are predominantly small, this may indicate obstacles for investors, such as resource obstacles, permitting barriers, investor confidence issues, financing obstacles—to name but a few.

As Table 4 shows, almost half of the projects developed by 2002 had small sizes, between 1 and 10 MW; the other half consisted of even smaller projects, below 1 MW (mostly biogas-based), and medium-size projects of up to 30 MW. All 19 medium-size plants were commissioned only after 1999. Detailed project-level data are not anymore available for the projects commissioned since 2002.

2.3. Types of project developers and motivations to invest

The type of investors contributing to technology diffusion and their reasons to invest constitute also important indicators for the maturity of the new technology's market. The extent to which large companies are present in the market indicates the size of the

Table 3
The use of various biomass resources and technologies by 2005 (based on [16,11]).

Technological designs	Secondary resources	Primary resources
Anaerobic digestion (biogas)	Dominant	–
Direct combustion	Dominant	Slowly increasing interest
Gasification	–	Few small demonstration projects
Pyrolysis	–	Research

Table 4
Sizes of biomass power projects (*Source*: [16]).

Sizes of projects	Number of projects	% in all projects
<1 MW (very small)	17	23%
<10 MW (small)	36	49%
<30 MW (medium)	19	26%
>30 MW (large)	1	~2%
Total number projects	73	100%

financial pool on which diffusion may potentially rely. The dominance of commercial projects, focused on profit-making, over strategic and niche projects indicates good prospects for a high-diffusion tempo.

Up to 1996/1997, the main developers of biomass power plants were owners/producers of secondary biomass resources, such as pulp/wood and paper companies, food and drinks companies, and wastes management companies harnessing biogas in the form of landfill gas. Investors from these industrial sectors commissioned more than 84% of the installed capacity by 1997 [18]. The rest of investments were made by agricultural cooperatives. These were all niche projects for the electricity consumption needs of project developers. The oil crises of the 1970s impinged these companies to find ways to reduce the energy price hikes on their bills [19]. Later, in the 1980s, industrial companies started to be required to take responsibility for their environmental impacts. For example, food and drinks companies had problems with water pollution from their production processes. The extraction of biogas from the organic matter present in residual waters was a solution to their environmental problems [18]. With time, more industrial processing companies realized that the generation of electricity based on secondary resources was a financially attractive option to reduce their environmental impacts.

Between 1997 and 2000, the picture of developers has started to change. Besides, the number of niche projects started to decrease and the total capacity of commercial projects increased, as it can be observed in Table 1; some of the commercial projects had also an important technology/resource-demonstration component. Four new groups of actors entered the market.

First, *energy companies and few large industrial technology corporations* started developing small strategic projects for demonstration purposes. They mainly tested primary biomass resources for direct combustion or gasification technologies. Almost all demonstration projects benefited of investment subsidies from the government, EU programs or/and regional authorities. In some of these companies, investors had also strategic, social motivations to invest; they were interested to raise the interest of local people in biomass, towards building networks for resource supply [19]. In addition, this group of developers has also started investing in commercial plants using secondary biomass resources in conventional direct combustion technologies. The number of commercial plants developed by them increased after 2000.

Second, *public actors* have also become equity investors, based on a new policy of engaging in public–private partnerships. Their main motivation to invest was strategic, aiming to help overcome investors' lack of confidence in the technology, resources and the price support system. The public actors investing equity are: the national energy agency IDAE, regional and local authorities, and public companies for economic development.

Third, *industrial production and food companies* generating organic wastes started to move away from the generation of electricity for the own consumption needs, and started investing in commercial projects. Finally, *banks and capital venture funds* also started investing equity in several projects [16]. Their investments are typically focused on commercial plants with conventional technologies and secondary resources.

The next two sections investigate the two categories of obstacles differentiated as impeding a more significant diffusion of biomass power in Spain.

3. Economic obstacles for biomass power generation

For any investor in electricity generation, the commercial terms under which the investment is made are of crucial importance, namely: (a) the clarity and reliability of the legal framework regarding the purchase contracts, and (b) the price per kWh likely to be received during the project's economic lifetime. Since

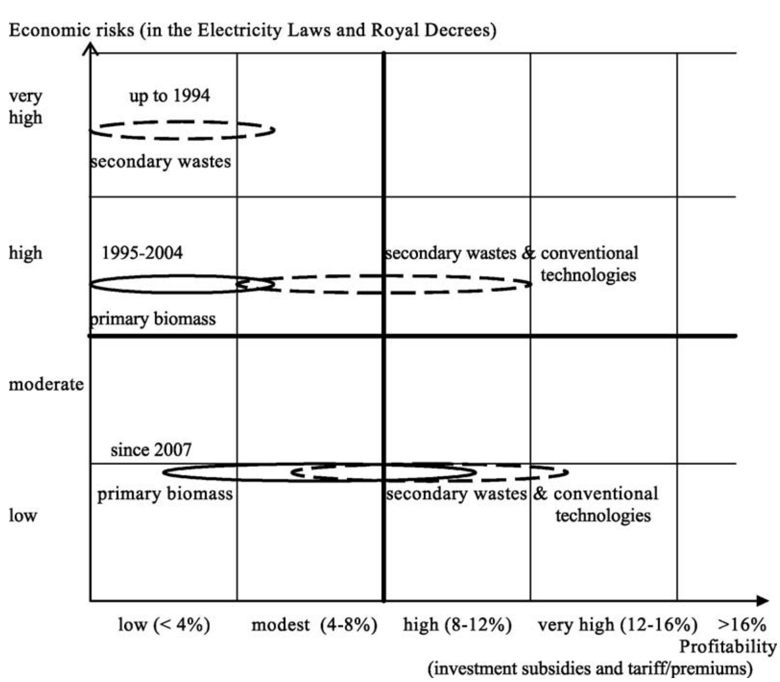

Fig. 1. The risk–profitability investment contexts for biomass power in Spain (*Source*: [16]).

biomass power technologies are more expensive than conventional-fuel technologies, political decision-makers – represented by the government and national parliament – introduced a series of support instruments to overcome the economic obstacles. Five legal frameworks can be differentiated in the period 1980–2008 in Spain. Nevertheless, the policy support was unable to overcome the economic obstacle of biomass power production until 2007.

The designs of the five legal support frameworks were characterized by combinations of risk and profitability levels, as shown in Fig. 1. The risks associated with the instruments were very high in the beginning, and lowered significantly only with the adoption of the Royal Decree 436/2004. The policy risks attached to these legal frameworks have always been the same for both secondary and primary resource-based biomass power. However, the profitability for power plants based on secondary biomass resources has always been higher than for primary biomass resources. The profitability ranges have started to overlap only with the adoption of the 661/2007 Royal Decree.

The main factor affecting the long-standing profitability problem of primary biomass resources is the conceptualization of *biomass resources* by *political decision-makers*. Policy learning regarding the complexities of biomass resources and types has been very slow, which can be seen in the definitions of biomass resources in the five legal frameworks. In the beginning, the frequent use of the term biomass/organic '*wastes*' by most stakeholders led political decision-makers to consider them as no different from industrial and residential wastes. The consequence was their categorization in the same 'technology group', in the first and second legal frameworks, offering them a very low-price support.

Besides, the perception dominated that biomass resources are quite *homogenous fuels*, from economic standpoint. When the third legal framework was introduced, 1997–1998, there was still no differentiation of resources between primary and secondary. The dominant perception was still that most resource types within these two categories are homogenous in terms of prices and markets; only energy crops were given a slightly higher price support.

The fourth legal framework adopted in 2004 differentiated for the first time several categories of primary resources and of secondary resources; however, economically, the price support differences among resource types remained very small. It was only in 2007, when a larger number of resource types were differentiated and the level of price support became more realistic, having in view the production costs of resources.

An important reason for the *persistence of the high risks attached to the price support* is the very slow policy learning among political decision-makers regarding investors' requirements on returns' predictability. When the issue of liberalization started climbing the political agenda, in the 1980s, it was considered that contractual and price arrangements have to be filled-in by the buyer and seller. Therefore, the legal instruments for renewables' support had to limit regulations on these aspects, to be in line with the market liberalization principles. However, political decision-makers strongly underestimated the importance of the high-economic risks induced for investors. While conventional electricity technologies have reasonable chances to survive liberalization, innovative technologies such as renewables can hardly attract investors' interest, when economic risks are added on top of the large number of other risks innovative technologies typically encounter, such as resource risks, technical risks, social, planning and various administrative risks related to their novelty [8,20,21].

It took political decision-makers in Spain a quarter of a century to change their conceptualization of biomass resources, understand their complexity, and to acknowledge the impacts of high-risk policy instruments on investors' interest in novel energy technologies. The following five sub-sections analyse the risk–profitability profiles of the five legal support frameworks and how they changed in time, as policy learning occurred among political decision-makers.

3.1. Economic support between 1980 and 1994

The first legal instrument for the economic support was the 82/1980 Energy Conservation Law. The price per kWh for biomass power was not specified in the law and had to be annually set by Order of the Ministry of Energy and Industry. Potential investors associated this with high risks, because ministerial orders can be easily and unilaterally modified by ministers. The length of purchase contracts with grid companies was also not specified in the law, which was again associated with high risks. Therefore, the legal framework for economic support applicable between 1980 and 1994 was characterized by very high-economic risks [16].

The profitability of biomass projects was very low during these years [16]. Projects could only be profitable when using direct combustion or anaerobic digestion technologies, and cost-free secondary biomass resources. The investment context for this group of projects is represented through a dashed-line oval in Fig. 1, indicating very high risks and low profitability. The risk–profitability characteristics of this first legal framework played an important role in fact that industrial production companies were the only type of project developers up to 1994.

3.2. Economic support between 1994 and 1997

In 1994 a new electricity law was adopted, as part of a more general legislative change towards the liberalization of energy production. Based on this, the Royal Decree 2366/1994 lowered somewhat the economic risks, after learning from investors about the risk perceptions regarding Ministerial Orders and (lack of) contractual provisions. The decree introduced a guarantee on purchase contracts for 5 years; this was seen to be in line with the investors' expectation on some minimum certainty on returns, and to satisfy in the same time the political conceptualization of liberalization, of moving away from long-term contracts. Prices for wind electricity were to be set by means of Royal Decree, passed by the national government every 4 years. This was associated with improved price reliability. However, contract risks were still present as the economic lifetime of biomass projects is typically at least 20 years, and the terms of contact renewal were not clear. The risks embedded in this second legal framework were, overall, still high [16].

The 2366/1994 Royal Decree categorised biomass resources in the same technology group with industrial and urban wastes, giving biomass power an only small price support per kWh (5.2–6.1€c/kWh). Not taking into account that biomass resources may be costly to procure, the decree restricted the chances for profitable projects to the same group of conventional technologies and secondary resources. When resources such as biogas and organic wastes from agricultural and industrial applications could be procured at low/no costs, the profitability of projects could reach up to 10–12% [16]. The risk–profitability investment context for this group is represented in Fig. 1 with a dashed oval at the 'high-risk' level.

This decree was operational only up to 1997 and, during these years, the few projects using primary biomass resources and/or gasification technologies could be economically feasible only with investment subsidies from national authorities, of up to 15% of the total investment costs [16]. The investment context for this second group of biomass projects is represented in Fig. 1 by means of a continuous-line oval at the 'high-risk' level; their profitability was seldom higher than 4%, and the main motivation behind their construction was technology and resource demonstration [22].

3.3. Economic support between 1997 and 2004

The third legal framework was applicable in the period 1997–2004 and was guided by the 54/1997 Electricity Law, adopted to advance the liberalization process. The special economic regime for renewable electricity was regulated through the 2818/1998 Royal Decree. This brought no changes in terms of contract risks and price risks although a new price design was introduced in an attempt to introduce market principles in the protected market of renewables. The 1998 Decree introduced two price formulas, at the choice of generators, if projects were smaller than 50 MW. The first was a 'market-based' option, and the second a 'revisable tariff' option. The hope of political decision-makers was that in time most investors would chose for the market-based option.

The decree differentiated for the first time two types of biomass resources – primary and secondary – with the former receiving an insignificant price increase. Secondary resources were defined as wastes from a primary use of biomass, especially manure, sludge from residual water treatment, forestry and agricultural wastes, biofuels and biogas. Primary biomass was defined as naturally occurring or purpose-grown plants younger than 1 year that can be used directly or through a transformation process.

The price support offered per kWh increased a little (6.2–6.5€c/kWh for the tariff option), and investment subsidies have also started to be offered, especially for projects using gasification technology and/or primary resources (maximum 30% of total investment costs). For this group of projects the profitability improved slightly, towards 5–6%. The profitability of projects using secondary resources and conventional technologies remained comparable to that typical during 1994–1996, of 4–12% [23].

Consequently, during 1995–2004, the risk–profitability contexts created by the two frameworks were highly similar, in spite of the price design changes. The continuation of the profitability patterns had to do with the fact that the 2818/1998 Royal Decree made again an unrealistic resource classification, when it categorised most primary biomass resources (un-used forest and agricultural residues) in the same group with secondary resources (organic matter from industrial and agricultural applications). The dedicated energy crops were finally placed in a separate group, but they were given low-price support having in view their high procurement and processing costs.

3.4. Economic support between 2004 and 2007

The economic support for renewable electricity changed more significantly with the adoption of the 436/2004 Royal Decree. Although sale contracts were still guaranteed only for 5 years, contract risks started to be perceived as low because of some important changes in the price design. The decree specified for the first time the price formulas for the entire lifetime of projects, allowing investors to calculate their returns with more reliability. Contractual prices were to be annually updated based on other Royal Decrees. However, although the 436/2004 Decree lowered the economic risks, it failed to increase the profitability of primary biomass power. The profitability of secondary resources was left unchanged. The risk–profitability profile of this fourth legal framework was not represented in Fig. 1 to avoid complicating the picture.

3.5. Economic support since 2007

The fifth legal framework is defined by the adoption of the 661/2007 Royal Decree applicable for biomass power, cogeneration and co-combustion with fossil fuels. The general provisions of the 54/1997 Electricity Law and the contract-length provisions of the 436/2004 Royal Decree remain the same, but new levels of price support are introduced. The 2007 Decree was adopted as a result of the political recognition that the legal price support was insufficient to stimulate investments based on primary resources and more innovative technologies, such as gasification and pyrolysis. Political decision-makers realized that, without a price support increase, the political goal for biomass installed capacity would not be achieved. The 2007 Decree lowered the goal to 1567 MW by 2010 [3] and introduced new tariffs and premium levels differentiated based on:

- the type of biomass resource, distinguishing among nine resource groups;
- the age of projects: projects 'younger' than 15 years receive more support;
- project sizes: projects smaller than 2 MW receive higher prices for all resource types.

The changes were applauded by the Association of Renewable Electricity Producers [2] and the government expects that numerous biomass projects can be developed with profitability of at least 7%. Profitability of up to 10% is now realistic for more types of primary resources. The risk–profitability profile of the fifth legal framework is represented through the ovals at the bottom of Fig. 1.

3.6. Concluding reflections on the economic obstacle

The economic obstacle is an important reason for the very slow increase in the biomass power capacity in Spain, and some of the diffusion patterns observed in Section 2. The unattractive risk–profitability profiles of the legal frameworks for price support during the 1980s and 1990s contributed to the dominance of projects based on (low/no cost) secondary biomass, and conventional technologies such as anaerobic digestion and direct combustions, which assume lower investment costs; they also had consequences for the limited investments committed by financially powerful actors.

Although energy companies and few technology corporations and banks entered the market, most of their projects were of small/medium scale and had strategic motivations, such as resource- and technology-testing, or raising interest among potential resource suppliers and local communities. Commercial projects enjoying the substantial financial involvement of large companies are crucial for speeding-up the diffusion of any new technology. Numerous large-scale projects – or at least investment plans – from these categories of actors have not emerged so far, in spite of the investment involvement of public actors, under private–public partnerships. Large companies entered the market in late 1990s with positive expectations, but remained so far 'at the entrance door'. Another important explanation for this is also the absence of reliable resource markets for biomass, which can continuously provide resources at prices that make biomass power production profitable under the applicable price support instruments. The aspects of biomass resource risks and prices are deeply connected, which makes the economic obstacle tightly related to the obstacle of resource potential and availability.

Consequently, a risk/profitability approach to the analysis of the policy instruments put in place to address the expensiveness problem of biomass power reveals why the instruments failed to remove the economic obstacle. Two factors emerge as explanations for this: the conceptualization of biomass resources by political decision-makers in the instruments used, and the desire that policy instruments be in line with market liberalization principles. The policy learning among political decision-makers on the nature and importance of these factors has been very slow. The changes in the definitions of biomass—with the profitability consequences they have, and in the risks embedded in the policy instruments have been incremental. A quarter of a century was needed in order to arrive at a risk/profitability profile of the supporting legal framework that reflects the heterogeneity of biomass and the investment requirements of commercial and financing agents.

4. Obstacles for the emergence of biomass resource markets

The diffusion of biomass power technologies assumes the reliable functioning of a multitude of resource markets, for the many types of biomass that can be used. These resource markets require the involvement of numerous types of private and public actors that normally operate in other policy domains than energy, under very different institutional regimes. Besides, certain resource markets may be affected by technical, natural, economic, and social factors and constraints that are rather resource-specific, and may require a resource-focused investigation and policy framework for obstacle removal. Nevertheless, there are also a number of constraints that are common across resources. This section focuses on the common obstacles to illustrate the need to coordinate a large number of actors and policy domains, in order to facilitate resource markets to emerge.

4.1. Uncertainties on the size of resource potential

The technical potential of the various resource types was for a long time only roughly known. An estimation published in 1997 [24] appeared later to have overestimated most resources, as shown in Table 5. The 2005 Plan for Renewable Energy, updating the one adopted in 1999, presented a different estimation of biomass potential; this estimation was also more detailed.

Differences in estimations may be due to changes in the assumptions underlying calculations. However, the consequences is that, as long as the national energy agency so frequently revises the resource potential estimations, both power generation investors and resource market investors are likely to associate high risks to these new business opportunities. One thing that all three estimations in Table 5 have in common is that the overall technical potential for primary biomass is higher than for secondary resources. Therefore, the profitability of projects based in primary resources is crucial for a substantial diffusion of biomass power in Spain.

A good estimation of the resource potential requires the involvement of sub-national public authorities and commercial/social agents from local and regional levels. Actors from a multitude of policy domains need to be involved: agriculture, forestry, wastes management. The involvement of most of these actors has only been attempted in the preparation of the Renewable Energy Plan update in 2005. This was the first time when a quantitative overview was made per region (Autonomous Community).

4.2. Economic factors

The first economic obstacle for the emergence of biomass-energy resource markets is *the price tag* attached to biomass resources, as compared to what power produces can pay, and what other commercial agents can pay for competing biomass applications. The supply price differs widely across resources, because of the differences in their seasonality, energy value, collections costs, transport, storage and processing costs. Menendez [25] mentions that the cost for clean forest wastes supply in Spain is between 3 and 4.8€c/kg. For clean agricultural wastes prices have an even much larger variation; for example, for straw they can vary between 1.2 and 9€c/kg. For woody agricultural wastes costs are above 3€c/kg [25]. Biomass power plants using such resources could only be profitable – under the price support per kWh electricity available up to 2007 – when biomass could be procured at 1.8€c/kg [26].

This played a crucial role in obstructing the development of markets for many types of biomass resources. Three key competitors can be distinguished in Spain: other energy applications such as biofuels for transportation; non-energy applications such as paper and furniture production; and demand for biomass exports. Resource competition discourages potential power generators.

This obstacle has been lowered with the adoption of the 2007 Decree for the price support of biomass power. However, for the more expensive resources, competition still remains. This obstacle could be further addressed in so far as public policies are able to affect the market processes that influence the deployment of biomass resources, e.g. by means of quota systems for the distribution of biomass resources, based on fuel security of environmental benefits' considerations.

A second economic factor regards the contractual arrangements for resource supply. Numerous investors are discouraged by certain characteristics of biomass, such as large spatial distribution and heterogeneity in quality. They fear the need to contract with a large number of small-quantity suppliers would attract complex and risky supply contracts; this would endanger the economic feasibility of biomass power projects [11].

4.3. Logistic factors

Improvements are still needed in the aspects of resource collection, transport, storage and processing [24]. These affect both the size and the reliability of the resource market. All these stages influence the energy quality of resources in time, impacting on the final production costs of biomass power.

Table 5
Estimations of biomass resource potential in Spain.

Types of biomass/million tons of oil equivalent (Mtoe/year)		*Source*: [24] IDAE, 1997	*Source*: [27] IDAE, 1999	*Source*: [11] IDAE, 2005
Primary resources	Energy crops	19.6	4.0	5.77
	Forest cultivation		1.7	
	Forestry wastes	13.8	1.4	1.37
	Woody-agricultural wastes		1.0	1
	Crop-agricultural wastes		7.9	7.86
Secondary biomass	Agricultural organic waste	2.2	0.25	2.95
	Industrial organic wastes		0.25	
	Biogas	1.6	0.55	0.38
Total biomass		37.2	17.15	19.33

4.4. Cultural factors

Cultural factors affect mainly the size of the available market. Numerous potential supplies of biomass do not see themselves as such. This holds for farmers, industrial companies, public agencies managing public lands and other private actors [11]. There is strong hesitance from farmers to switch to a completely new type of cultivation, such as dedicated energy crops, for which costs and profits are yet unknown. Even farmers – who already have biomass wastes as their by-product – have been so far reluctant to initiate or respond to contacts for biomass supply to power producers [27].

Most potential resource suppliers are not traditional actors in energy supply chains. Building new business relations with such completely different economic agents as commercial power generators means stepping out of the boundaries of their perceived 'action domain'. Public agencies for forest management are also not at ease with the expectation on them to expand their action domains, as they are not used to plan and act based on energy-use criteria.

In conclusion, political decision-makers developed a legal framework for the price support of biomass power production; but they completely ignored for a long time the importance of wider institutional and policy frameworks for the stimulation the biomass resource markets, that go beyond the energy policy domain. It was assumed that resource markets will emerge through the spontaneous initiatives of private actors, once demand for biomass power is created. The failure to understand the nature of biomass resources, their production channels and supply complexities, and the multitude of new actors that need to be involved, have been at the core of these second category of obstacles.

5. Policy learning and political will to address diffusion obstacles

The interested investors and the National Association for Renewable Energy Producers (APPA) regularly informed the administrative and political authorities about the obstacles for biomass power and lobbied for policy changes. The analysis of the 1999 and the 2005 Renewable Energy Plans suggests two important things.

First, policy learning among key national administrative actors regarding the existence and magnitude of numerous obstacles discussed in the previous section has occurred already since the 1990s, and improved in time. The energy agency IDAE and the Ministry for Industry and Energy responsible for energy policy mapped several obstacles in the 1999 Plan for Renewable Energy, proposed a series of measures to address them and proposed budgets for their implementation. In 2005, the new Plan for Renewable Energy, updating the 1999 version, acknowledged the still "practical absence of biomass markets" [11] and presented a more comprehensive overview of obstacles. This indicates further policy learning regarding obstacles that were earlier insufficiently appreciated. Besides, policy learning is also reflected in the adoption of concrete implementation plans that assign not only the needed budgets for the proposed measures but also the public actors responsible and the time horizons for implementation. The plan incorporates a series of policy recommendations formulated during the 2004 National Congress of the Association of Renewable Energy Producers [1]. It also reiterates the need to improve the profitability of biomass power projects.

Second, political decision-makers took a long time to react to the policy recommendations of the policy personnel of IDAE and the Energy Ministry. This may be either due to the lack of political will to finance measures for obstacles' removal, or due to a lack of policy learning effects as a result of the more frequent changes of individuals in the national parliament and government after elections. Although the government adopted the 1999 Policy Plan for Renewables, the necessary budgets for the implementation of most of the measures suggested were not approved.

Consequently, most measures remained un-implemented, including the revision of the price support instruments for a higher profitability of biomass power plants. The efforts of (potential) biomass investors to convince political decision-makers of the importance of a lower risk investment environment led to small but continuous reductions in policy risks, as the legal frameworks were revised. The efforts to convince political decision-makers about the technical and economic heterogeneousness of biomass resources and requirements for more financially attractive and comprehensive policy interventions have taken, however, a long time to produce effects.

Meaningful changes in the attitude of political decision-makers towards biomass power can only be signalled since 2005, when the new Policy Plan for Renewables started clearly that there is a high probability of failing to achieve the 2011 goal of 3100 MW biomass power capacity. The first political reaction to this was the establishment in 2005 of an Inter-Ministerial Committee for Biomass, where a variety of administrative actors are represented. The second important change was the reduction of the economic obstacle through the adoption of the 661/2007 Royal Decree allowing for higher electricity purchases prices for all types of biomass resources. This increases the part of the large technical potential of primary biomass resources that is economically exploitable.

The 2005 Policy Plan finally acknowledges the crucial role of coordination across policy domains and actors at various governance levels in overcoming the obstacles for reliable resource markets. For example, it is emphasized that close coordination is needed among the agricultural planning instruments, industrial development policies, spatial planning strategies, legislation on the responsibilities of public actors, and the energy policies and laws in Spain [11]. The new Inter-Ministerial Committee is expected to make sure that such coordination is implemented.

In order to address the economic obstacles in the biomass resource markets related to the heterogeneity and territorial dispersion of resources, the government asked the Ministry of Agriculture and the (new) Ministry of Industry Commerce and Tourism to develop a standard contract suitable for contracting with large numbers of small-size resource suppliers. Such contracts are meant to ensure power producers a long-term, low-risk supply of sufficient biomass resources at predictable prices.

The government also promised financial support for investors in companies, equipment and infrastructure for the collection, processing and transport of biomass resources to power plants. This is planed to be implemented in parallel with awareness campaigns on the benefits of engaging in these new business areas, and with information mechanisms focusing on the technical training of those deciding to become biomass suppliers. These measures are meant to contribute further to the reduction of the economic obstacles for the emergence of biomass resource markets.

The implementation of the 2005 policy measures is still ongoing, and the application of the 2007 Royal Decree is too recent to support evaluations of diffusion impacts. The design of the updated policy framework for biomass power diffusion appears on paper to be economically attractive and institutionally comprehensive—for the first time, after a quarter of a century of policy learning and experimentation.

6. Conclusion

This paper investigated the patterns of biomass power diffusion in Spain and discussed the obstacles influencing them and the disappointing diffusion results observed by 2008. Empirical analyses revealed that the 'prima facie culprits' for the level and patterns of biomass power deployment are formed by the persistent economic obstacle for biomass power generation, and a number of obstacles preventing emergence of biomass resource markets. The (very) high investment risks and low profitability characterizing the economic policy instruments up to 2004, in combination with the lack of reliable markets for biomass resources, led to the dominance of small-size projects, owned mainly by generators/managers of biomass secondary resources.

These factors also contributed to the delay of commercially motivated investments made by financially strong companies interested in electricity generation as mainstream activity—that have a higher potential to drive the diffusion of a new technology in a higher tempo. When investment risks lowered, with the adoption of the new legal frameworks in 2004 and 2007, new financially strong companies entered the market. However their investments have been small in terms of both number of projects and installed capacity because of the un-satisfactory levels of profitability, and the continuous procurement risks in the still immature resource markets.

The low profitability of projects led also to the dominance of biomass power plants based on secondary resources and obstructed the emergence of resource markets. Besides, it led to the dominance of less efficient but cheaper conventional-conversion technologies: direct combustion and anaerobic digestions. The low profitability of biomass power generation impeded the demonstration of new primary resources, such as energy crops, and of innovative technologies such as gasification and pyrolysis.

The persistence of the economic obstacle for more than two decades and the lack of policy attention for the resource markets, were induced by the conceptualization of biomass by political decision-makers as a relatively homogenous resource—which does not need much price differentiation, nor special policy measures for its supply stimulation due to its 'waste' nature. In the same time, there was a strong political preference to use policy instruments in line with market liberalization principles.

Policy learning among political actors was slower than among administrative actors. This can also be seen in the late acceptance of budgets for wider policy measures meant to remove the numerous obstacles to the development of resources markets, which require strong policy coordination and innovation across numerous policy domains and across governmental levels; such measures have been only implemented since 2005. Likewise the slower policy learning can be seen in the very late adoption – in 2007 – of a support instrument offering adequate profitability to biomass projects using all types of resources.

Nevertheless, important question marks lurk on the horizon regarding the continuity of policy support, which still cast shadows of uncertainty on potential investors and on the future of biomass power production in Spain. The 661/2007 Decree mentions that the generous price support offered is only applicable for projects which will enter in operation before 2010. The main motivation of adopting this instrument was to encourage the achievement of the political goal of 1567 MW by 2010, and the level of price support will be revised depending on the installed capacity achieved in that year, as well as the new goal for 2020 to be adopted by then. Therefore, all scenarios are possible—price support may decrease, increase or stay the same.

In conclusion, this paper showed the usefulness of studying the diffusion of renewable energy technologies by means of diffusion indicators that can underpin the investment interest among commercial agents. Besides it also argued and illustrated that the analysis of policy instruments by means of their risk and profitability characteristics enables a good understanding of the diffusion patterns observed, the workings of diffusion obstacles, and the diffusion outcome of the technology studied.

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