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Biopower from direct firing of crop and forestry residues in China: A review of developments and investment outlook

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ABSTRACT

This paper reviews developments in the direct-fired biomass power sector and provides an up to date investment outlook by calculating the Net Present Value of new investments, and the appropriate level of Feed-in-Tariff needed to stimulate future investment. An overview is provided of support policies, historical growth in installations, and main market players. A number of data sources is combined to build a database with detailed information of individual biopower projects. This data is used to describe technological and market trends, which are used in a cash flow model to calculate the NPV of a typical project. The NPV for new projects is estimated to be negative, and investment should be expected to stall without proper policy intervention. Increasing fuel prices, local competition over biomass fuel resources, lower than expected operational performance and a downturn in carbon markets have deteriorated the investment outlook. In order to ensure reasonable profitability, the Feed-In-Tariff should be increased, from the current level of 90.9 € MWh^{-1}, to between 97 and 105 € MWh^{-1}. Where possible, government organizations should help organize demand for the supply of heat. Local rural energy bureaus may help organize supply networks for biomass fuels throughout the country, in order to reduce seasonal and local fuel scarcity and price fluctuations.

Abbreviations: CDM, clean development mechanism; CER, certified emission reduction; CF, capacity factor; CFB, circulating fluidized bed; CHP, combined heat and power; FIT, feed-in-tariff; GHG, greenhouse gas; MOA, ministry of agriculture; MSW, municipal solid waste; NBE, National Bio Energy Co., Ltd.; NDRC, National Development and Reform Commission; NPV, Net Present Value; VAT, value added tax.

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1. Introduction

China has ambitious development plans for renewable energy, with an overall target of 15% of primary energy from renewables by 2020, and strong growth in renewable power generation [1]. Chinese installations of renewable forms of power have in recent years grown to be the world's largest [2], with particularly rapid increases in wind and solar PV installations (Table 1).

This development has been the subject of much research, with analysts looking into the role of e.g., the institutional framework [3–6], financial parameters of renewable power projects [7–10], and technological capabilities in the equipment manufacturing industry [11–15]. By comparison, biomass power has grown less rapidly (Table 1), and has received less attention, in particular concerning technological and financial parameters. A small number of analysts have previously commented on the cost and required subsidy levels for biomass power in China. These have been rather rough estimates [16,17] or, as we will demonstrate, require an update against recent developments in technological and financial parameters [17,18].

This paper describes the recent development of China's biopower sector, focusing on developments in technological and financial parameters. These parameters are used to calculate 1) the Net Present Value of current investments in a typical Chinese biopower project, and 2) minimum levels of Feed-In Tariffs required to keep Net Present Value positive. Results of this exercise highlight low returns and high risks associated with current investment in biopower projects in China, explaining at least in part the relatively slow development of this form of renewable power.

This analysis is focused on ‘crop and forestry residue based’ biopower, a categorization used in Chinese policy to set it aside from biogas and MSW based forms of biopower. This is the largest form of biomass power in China, both in terms of current installations, and in future policy targets (Table 1). It is further focused on grid-connected applications (‘main activity producers’) as opposed to the in-house use of biopower (‘autoproducers’). The latter type consists of numerous, small scale boilers, on which limited data is available. It is further not covered by government subsidies, nor is it expected to increase substantially in the foreseeable future [16,19]. Lastly, it is focused on direct-fired applications and ignores gasification, as grid-connected gasification is estimated to make up a few dozen MW at most [19]. For more information on these other technological pathways, please see the overviews provided by Zhao and colleagues [16] or the ERI [19].

2. Method

The economic desirability of a project can be evaluated using the Net Present Value method. This entails summing up positive and negative cash flows arising from the project. The cash flows are calculated on an annual basis, with future cash flows discounted to give their equivalent present value. The decision to invest is made when Net Present Value is at least zero. At this level, the internal rate of return (IRR) is equal to the discount rate [20].

Although the minimum IRR required for an investment to occur usually depends entirely on investor preference, Chinese regulations on investment in the power sector has set a benchmark IRR of 8% (post-tax) as feasible and reasonable [21] and this value is used to discount cash flows in the NPV estimation here. Project cash flows include investment, operational cost, production level, revenue and tax levels.

The proper (range of) values to be used in the NPV estimate have been determined through 3 data collection steps; 1) a review of policy documents and scientific literature on China's biopower sector; 2) compilation and analysis of a detailed database of individual Chinese biopower projects, followed by 3) a round of expert interviews correct or verify and enrich preliminary results from steps 1 and 2. A total of 19 experts were interviewed, including 7 academics, 2 market analysts, 5 representatives from industry and 5 representatives of government organizations.

The database of biopower projects in China (appended as Supplementary material) was compiled from the following data sources:

1. CDM applications

A large majority of Chinese biopower projects has applied for registration as a Clean Development Mechanism (CDM) project. Applications are publicly available [22] and include information on location, developer, capacity, boiler brand and

Table 1 – Chinese renewable power capacity (MW), actual and targets, 2000–2020.

	2000	2005	2010	2015	2020
Wind	340	1,260	44,781	100,000	200,000
Solar	19	70	800	35,000[a]	50,000
Biopower (all), of which:	1,100	2,071	4,952	13,000	30,000
Crop and forestry residues based[b]	1,000	1,741	3,452	8,000	24,000
Biogas based	0	30	1,000[c]	2,000	3,000
MSW based	100	300	500[c]	3,000	3,000
Total, non-hydro renewables	459	3401	50,553	148,000	280,000
Total, all forms	319,320	517,180	966,410	1,465,000[d]	1,750,000[d]
Non-hydro renewables (% of total)	0.14%	0.65%	5.23%	10.1%	16.0%

Notes: grid-connected capacity only; a) the 12th Five Year Plan originally included a 21 GW target for solar; this was increased to 35 GW in early 2013 [78]; b) includes bagasse power; c) target rather than actual; d) forecast rather than target.
Sources: wind power: [57]; biopower: [16,55]; solar PV: [79]; totals: [55]; 2015 and 2020 targets: [1,80].

technical specifications, construction cost, estimated fuel consumption etc.

2. Government subsidy reports

The ‘National Development and Reform Commission’ (NDRC, China's ministry for economic and energy planning) periodically publishes data on power production and subsidies granted to individual renewable power projects [23]. These lists were used to verify which projects were operational, since when, and how much electricity was generated.

3. Company reports and websites

DP Cleantech, China's largest boiler designer, provided an up to date project reference list. Wuhan Kaidi, China's second largest boiler designer and biopower plant operator, publishes regular updates in the form of annual and quarterly reports on its website [24–26]. The database was further verified and updated with annual reports and news items available via websites of other project developers and boiler manufacturers.

The database contains a total of 236 projects. In figures presented in this paper, data is differentiated between ‘operational’ and ‘planned’ projects. ‘Operational’ projects were confirmed to be delivering power to the grid, using either NDRC reports, or annual reports or news items on company websites. ‘Planned’ projects are under construction, or have been announced in company reports or CDM project applications. The 236 projects in our database totaled 2019 MW in 2010, or 58% of that years' operational capacity in crop and forestry residue based biopower in China, and 6173 MW, or 77% of the planned capacity in 2015 (see also Table 1, numbers include operational and planned projects).

Financial values throughout this paper are reported in euro, whilst most of the original data was reported in Chinese Yuan Renminbi (CNY). A single fixed exchange rate of 8.25 CNY €$^{-1}$ has been used (2012 average [27]). Inflation is corrected for using CNY based price indices [28].

3. Results

This section starts with background information on policy stimulus and guidance (Section 3.1), historical growth of installed capacity (Section 3.2), and project developers and boiler manufacturers active in China's direct fired biopower sector (Section 3.3).

The values and ranges of parameter values to be used in calculating project NPV are explored with a description of trends in technological parameters (Section 3.4), and the market environment (Section 3.5).

These results are combined to calculate the Net Present Value of new investment in a typical biopower project, and the required minimum level of Feed-In-Tariff to keep NPV positive (Section 3.6).

3.1. *Policy stimulus and guidance*

The Renewable Energy Law of 2005 has been credited as a milestone in Chinese government stimulus for RE [29]. This was a comprehensive framework law, with development targets and financial mechanisms detailed shortly after, in particular in the ‘Medium and long term RE development plan’ [30] and the ‘Regulations on renewable energy price and cost-sharing management’ [31].

Crop and forestry residue based power generation is targeted to reach 8 GW, with a production of 48 TWh, by 2015. Biogas and MSW based forms make up the remainder for the overall biopower target of 13 GW and 78 TWh by 2015.

In January 2006, a feed-in tariff (FIT) for biopower was set at 30.3 € MWh^{-1} on top of the ‘standard grid price’ [31]. This standard is the price for power from de-sulfurized coal fired power generation, which is fixed at a government determined level and varies between 31.8 and 59.9 € MWh^{-1} over different provinces (prices since 2011) [32]. Accounting for provincial level prices and installed biomass capacity, the average grid price received was 50.3 € MWh^{-1}, excluding FIT, or 80.6 € MWh^{-1} including FIT (incl. 17% VAT) [32,33]. The FIT is awarded during the first 15 years of operation the project, the standard grid price applies afterwards [31].

Projects in operation prior to January 2006 were not eligible for the FIT. Projects that co-fire more than 20% conventional fuels have not been eligible either. Co-firing does not fit MOA's policy agenda for sustainable rural development, as ashes from co-fired plants cannot be returned to agricultural soils for fertilization, increasing already problematic levels of chemical fertilizer use. A lack of metering technology for establishing levels of co-firing has further raised concerns about possible fraud with reported levels of biomass use, and corresponding levels of FIT requested [19].

In 2010, the FIT was raised to 90.9 € MWh^{-1} (total, not on top of standard grid price, and equal across all provinces) [34]. All projects eligible for the FIT introduced in 2006, including existing projects, have been receiving the increased FIT [23,34].

The guideline for project size is between 12 and 30 MW [35,36]. Larger turbines can be more fuel efficient, but the larger fuel collection area increases transport distances, which reduces environmental benefits.

To prevent competition over biomass resources, regulations suggest a maximum of one project per county, or to develop no further projects in a 100 km radius of an existing project [36]. This implies an exclusive resource collection area with a radius of 50 km for each project, which has been suggested to be sufficient for a 30 MW project [37].

Policies have also addressed the need for compacted fuels (pellets or briquettes), including the establishment of an infrastructure for fuel collection, processing and distribution [1,30,38]. Key points of China's biomass power policies are summarized in Table 2.

3.2. *Installed capacity*

Since the enactment of the ‘Renewable energy law’ of 2005 and the ‘Renewable energy price and cost-sharing management’ of 2006 (Table 2), there has been a relatively rapid development of biopower plants. China's first biopower station started operations in December of 2006. Installations have accelerated to circa 1 GW of additional capacity in recent years, and appear on track to meet the government target of

Table 2 – Key points of Chinese policies for biomass power.

2005	**Renewable energy law [81]**
• State council will set RE development targets, lower level governments are to draft development plans accordingly	
• Compulsory grid connection and full purchase of renewable power, gas and heat	
• Periodically increased renewable energy surcharge for household use: initially 0.12 € MWh^{-1} in 2006; has been 1,82 € MWh^{-1} since September 2013 [82,83].	
2006	**Renewable energy price and cost-sharing management [31]**
• Biopower pricing determined as 1) a price agreed in tendered concessions; or 2) feed-in-tariff of 30.3 € MWh^{-1} on top of standard grid price. Concession prices may not exceed standard FIT	
• Co-firing projects not eligible if conventional fuels exceed 20% (heating value) of the fuel mix	
2007	**Medium and long term RE development plan [30]**
2008	**11th Five year plan for Renewable Energy [80]**
• By 2010, 10% of energy should come from renewables; by 2020 this should be 15%	
• Renewable portfolio standard (RPS): power companies with more than 5 GW of generation capacity should have 3% of RE (excl. large hydro) by 2010, and 8% by 2020	
• Biomass power target of 5.5 GW, producing 24 TWh by 2010, and 30 GW by 2020.	
• Production of briquettes and pellets should reach 1 Mt by 2010 and 50 Mt by 2020	
2007	**Agricultural bioenergy industry development plan (2007–2015) [38]**
• Production of briquettes and pellets should reach 20 Mt by 2015	
• Develop briquetting technology and establish pilot programmes for crop straw collection, transport, storage and pre-processing.	
2008	**Strengthening the environmental impact assessment management of biomass power generation projects [35]**
• Suggests higher capacity turbines, in principle no smaller than 12 MW	
• Environmental impact assessment must consider effects of collection, transportation and storage of biomass fuel and other raw materials.	
• Projects must adhere to standards for emissions to air	
2010	**Management of the construction of biomass power generation projects [36]**
• Consider the availability of biomass resources in planning of biomass power projects.	
• As a guiding principle, develop only one project per county or within a radius of 100 km	
• As a guiding principle, no projects of a scale of more than 30 MW	
2010	**Improved pricing policy for agriculture and forestry biomass power [34]**
• Feed-in-tariff (FIT) equalized nation-wide and raised to 90.9 € MWh^{-1}	
2012	**12th Five Year Plan for renewable energy [1]**
• Biopower target of 13 GW by 2015, with an annual power generation of 78 TWh. No 2020 target is specified. For crop and forestry residue based power, the targets are 8 GW and 48 TWh	
• Production of briquettes and pellets should reach 10 Mt by 2015	

8 GW by 2015 (Fig. 1). In addition to the projects included in Fig. 1, there is circa 1700 MW of bagasse power generation capacity installed in China's sugar cane processing plants [16,19]. This capacity is used to supply in-house power and heat demand, and is not expected to grow significantly in the foreseeable future. Other forms of crop and forestry residue based power generation, including e.g., gasification are very small in terms of installed capacity [16,19].

3.3. *Project developers and boiler manufacturers*

3.3.1. *Project developers*

The developer and operator of China's first biopower plant is the National Bio Energy Co., Ltd. (NBE; now part of the State Power Group Co., ltd). NBE's expansion was a main driver for market growth in the following few years. In 2009, NBE operated 63% of the 901 MW of operational biopower plants in

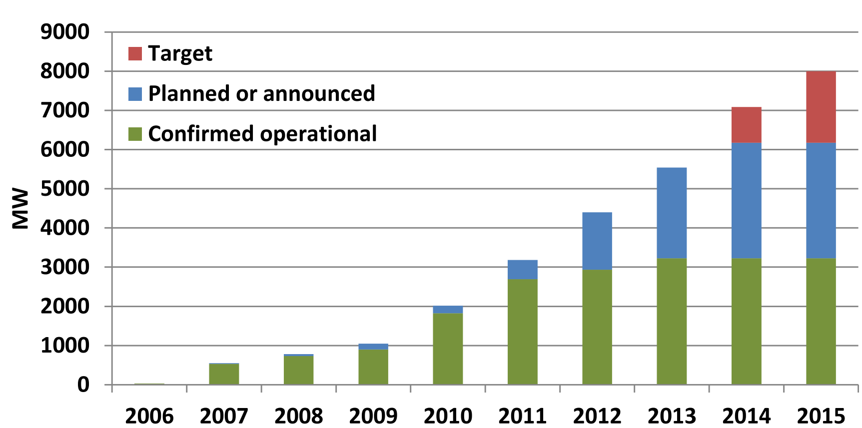

Fig. 1 – Cumulative capacity of direct-fired biopower projects in China. Notes: grid-connected applications only; 'Target' is the 12th Five Year Plan target for all forms of 'crop and forestry residues based biomass power', including gasification and bagasse power. Source: [33].

China. NBE remains the market leader today, with circa one-third of all biopower stations (Fig. 2).

The second largest developer is Wuhan Kaidi Electric Power Co., Ltd. (Kaidi). This company has traditionally been engaged in the design and turn-key development of coal-fired power plants. In recent years, it has specialized in environmental technologies related to power generation, including clean coal technologies, flue gas treatment and MSW incineration plants. In 2010, Kaidi opened its first biomass power station. By the end of 2013, it had 19 plants with a combined capacity of 518 MW in (trial) operation, and another 26 in the planning phase (Fig. 2).

China's big state-owned power companies (the so-called ‘Big 5: CPI, Datang, Guodian, Huadian and Huaneng), which are the largest developers of wind and solar projects [39], are relatively inactive in biopower generation (Fig. 2). Interviewees explained this as due to a preference for larger project sizes, and the better predictability of resources (wind speed and sunshine hours), when compared with biomass fuel supply and prices. The remainder of projects are developed and operated by a very diverse group of state owned and local utilities, operating between one and four projects each.

3.3.2. *Boiler designers and manufacturers*

DP Cleantech has been market leader since China's first biopower plant was constructed by NBE. DP Cleantech and NBE were subsidiaries of a mutual parent company called Dragon Power Group Co., Ltd. DP Cleantech designed NBE's power plants, with boiler manufacturing outsourced to Jinan Boiler Group, which was acquired by the Dragon Power Group in July of 2007 [40]. In 2010, Dragonpower split and NBE and DP Cleantech became independent companies. They remain each other's most important business partners, although both have diversified their supplier or client portfolio. Kaidi designs the boilers and rest of the power plants it operates itself, with boiler manufacturing outsourced to a number of domestic firms, including Hangzhou Boiler Grp., Jiangxi Jianglian and Suzhou Hailu. A third boiler brand used in a relatively large number of projects is Wuxi Huaguang. Technical details on boilers used in China's biopower projects are included in the database provided as Supplementary material with this article.

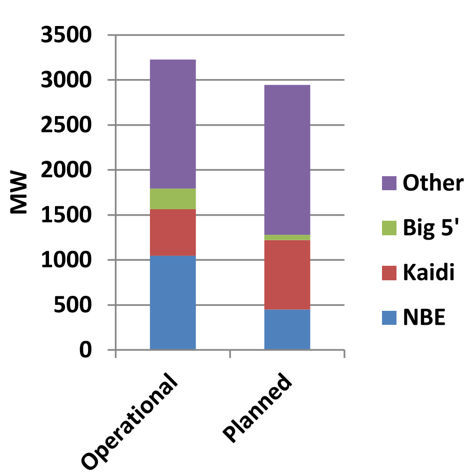

Fig. 2 – Operators of biopower projects in China. Data source: [33].

3.4. *Technological trends*

This section describes project scale, the use of either vibrating grate or circulating fluidized bed designs, as well as developments in boiler pressure, project construction cost and realized operational performance.

3.4.1. *Project scale*

China's biopower policies favor purely biomass fired power plants (see Section 3.1), which have traditionally been smaller scale plants (several to several dozen MW) [41]. Larger capacity boilers will be able to attain higher energy efficiency [42], but require a larger resource collection area, which increases fuel transport distance and cost, and reduces GHG reduction benefits [41]. The optimum size suggested by policy is between 12 and 30 MW (see Section 3.1), and developers have generally adhered to this guideline (Fig. 3).

Compacting biomass fuels into pellets increases the energy and cost efficiency of long range fuel transport [43,44]. In 2012, total global pellet production was approximately 22.4 Mt, of which 8.2 Mt were traded internationally [43]. This has enabled larger scale biopower projects, e.g., the Tilbury power station (750 MW) and Drax power station (660 MW) in the U.K., both of which will rely largely on imported pellets [45,46]. Chinese imports and exports of pelletized fuels are estimated to be very limited [47].

Domestic pellet production was circa 3 Mt in 2010 [43], and is targeted to reach 10 Mt by 2015 [1]. Only part of these fuels is meant for use in power generation, however.

China's policy plans are strongly aimed at the production of biomass briquettes, which should replace coal and unprocessed biomass still commonly used in household stoves in rural China [38].

3.4.2. *Boiler design: grate firing or fluidized bed*

Two different designs for the combustion of biomass fuels have been used in China: water-cooled vibrating grate and Circulating Fluidized Bed (CFB). Both technologies have their respective advantages and disadvantages in the utilization of biomass fuels (for an overview, please see e.g., [48–50]). Between the two, CFB boilers have a greater need for a more constant fuel supply ([48,51]; an issue further dealt with in Section 3.4.5).

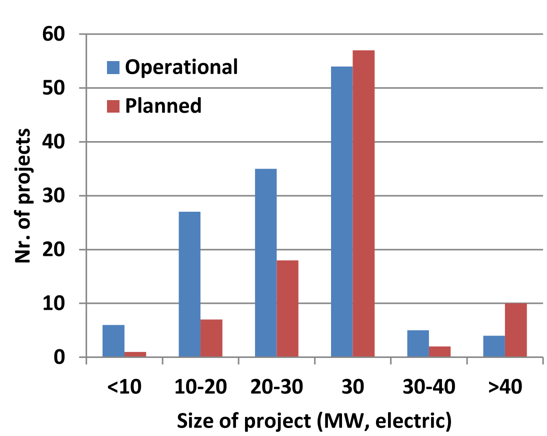

Fig. 3 – Scaling of direct-fired biopower projects in China. Data source: [33].

Three boiler brands active in China use a water-cooled vibrating grate design: DP Cleantech, Wuxi Huaguang and China Western Power. Remaining manufacturers use a CFB design. These manufacturers all have experience with coal fired boilers, and CFB is the most popular design in thermal power generation in China. Amongst others, this is because China has large amounts of coal with high sulfur content, and CFB boilers allow for cost-effective emission control of sulfur oxides, by mixing limestone in the fuel mixture [52].

3.4.3. *Boiler steam pressure*

Boilers that operate at higher pressure and temperature can achieve higher fuel efficiency but are more difficult to engineer and tend to be more costly. In biomass boilers, alkali and chloride corrosion is an issue in particular at higher temperatures and pressure [53]. Such boilers therefore require advanced, costly alloys with high resistance to such corrosion [53].

DP Cleantechs boilers, which were the most popular between '06 and '09, is a high pressure, high temperature design (9.2 MPa and 540 °C). Domestic manufacturers have relied on low and medium pressure designs (ca. 3.8 and 5.3 MPa) for several years. The first domestically produced high pressure boilers (ca. 9.2 MPa) came online late '10 and early '11 (Fig. 4). Kaidi has developed a super high pressure (13.3 MPa) CFB boiler, and uses it in six power plants that became operational over the course of 2013. Earlier power plants developed by Kaidi use its 5.3 MPa design [33]. Operators in China have continued to use a diverse mix of low, medium, and high pressure boilers (Fig. 4). Increased market share of domestic suppliers of low and medium pressure designs has led to a decrease of the average pressure of boilers used. The introduction of Kaidi's super-high pressure design in 2013 has reversed this trend (Fig. 4).

3.4.4. *Construction cost*

Construction costs for biopower projects in China have had a downward trend, from 1400 € kW^{-1} in '07 to circa 1150 € kW^{-1} in '12 (Fig. 5). Interviewees attributed the downward trend mostly to increased competition, i.e., more suppliers and a larger number of projects.

No demonstrable differences in cost were found between CFB of grate fired designs, or projects with different boiler pressures. Even Kaidi's super-high pressure design has costs close to the market norm of 1150 € kW^{-1} in '12 [33]. Despite the downward trend in recent years, interviewees indicated that a significant further decline would be unlikely.

3.4.5. *Operational performance*

Operational performance of a power plant can be reported as capacity factor, i.e., actual power production, divided by the amount of power that would have been produced if the plant constantly operates at full load.

Power production may be halted for routine maintenance. Maintenance is also needed in the case of equipment failure, and therefore depends on technological quality. Capacity factors can also be reduced by curtailment, i.e., when the grid operator has no need for power from a specific plant and denies it grid access. Lastly, production may be ceased when fuel is unavailable or priced at a level that does not allow for profitable production [54].

The Chinese policy target, of 48 TWh of production with 8 GW of installed capacity, implies a capacity factor of 68.5%. This is ambitious, as even coal fired power plants typically achieve a capacity factor of between 60 and 70% (annual average, calculated on nameplate capacity), both in China and the US [55,56]. CDM applications for Chinese biopower projects predicted a capacity factor of 62.4% on average [33]. Actual operational performance has lagged behind either of these expectations. The average capacity factor was 55.0%, with a wide variation in performance between individual projects (Fig. 6).

Interviewees indicated that curtailment was not an issue. Curtailment is a severe issue for wind power in China, due to the intermittency of production and limited transport capacity of power lines between generation and load centers [57]. Biopower is far less intermittent, and power plants are of smaller sizes and closer to load centers than wind farms are.

Technological choices did influence operational performance. Projects using grate firing designs performed significantly better than those using CFB boilers, at 62.9% versus 50.4%, respectively [33]. Boilers from the three biggest brands

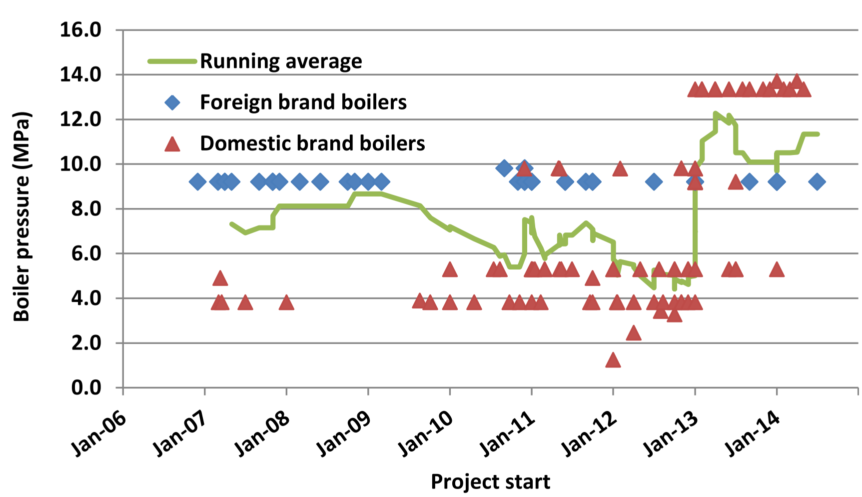

Fig. 4 – Steam pressure of biopower projects in China. Notes: includes operating and planned projects; includes 126 projects for which boiler pressure data was available. Data source: [33].

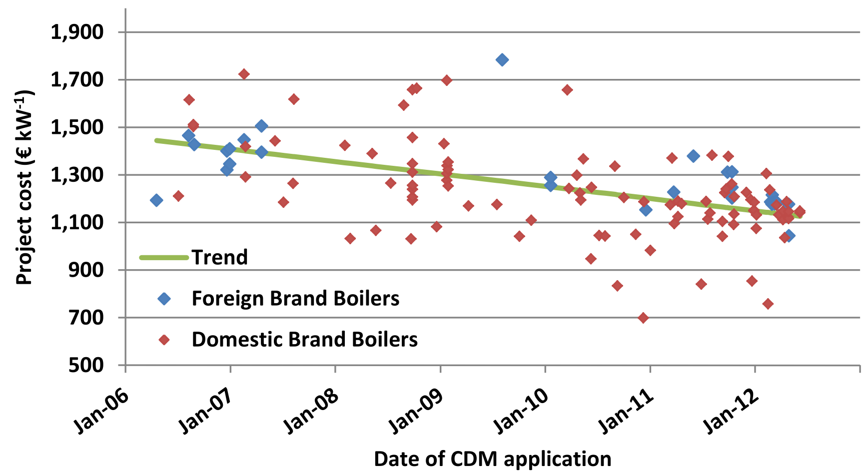

Fig. 5 – Construction cost of direct fired biopower projects in China. Notes: includes 163 projects for which construction cost data was available; note that the date is of the CDM application, not project start; inflation is corrected for using CNY price indices [28]. Data source: [33].

by market share outperformed those from other brands (Fig. 6). Nevertheless, each of these brands had strongly varying performance in different projects. Even amongst the projects using technology from DP Cleantech, arguably the most tested and matured technology in the Chinese market, a significant number of projects performed very poorly (Fig. 6). If this low capacity factor is indeed not due to poor technology, i.e., downtime due to maintenance requirements, fuel supply problems are likely an issue. This would be consistent with the observation that projects using CFB boilers perform more poorly. This type of boiler requires more constant fuel supply as these cannot easily operate at partial load, because the bed requires a minimal amount of heat input to maintain (optimal) combustion conditions [48,51]. Grate firing systems have no such requirements. Problems with fuel supply impacting operational performance was acknowledged by nearly all interviewees, and is further investigated in Sections 3.5.1 and 3.5.2.

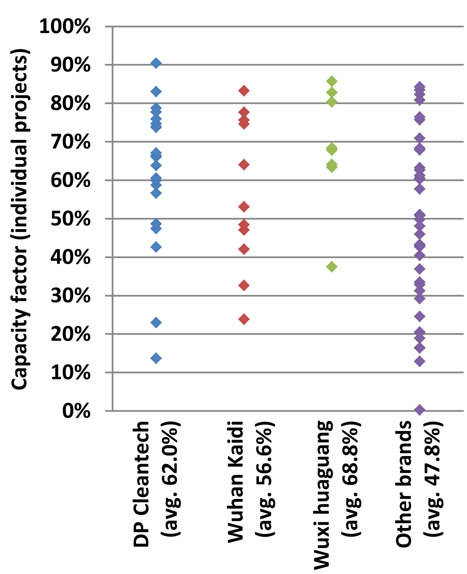

Fig. 6 – Capacity factor of individual biopower projects, by boiler brand. Notes: Capacity factor is operational performance data based on NDRC's subsidy report for the period Oct. '10 – Apr. '11 [23]. All projects were operational for the entire reporting period, as we included only those projects that were reported to be operational in the previous edition of the subsidy report as well. Data source: [33,23].

3.5. *Market environment*

Here the aspects of the market environment that influence the financial performance of biopower projects are discussed, including fuel availability, fuel pricing, sales of heat, and sales of carbon credits.

3.5.1. *Fuel availability and competition*

The NDRC has assessed the availability of China's crop and forestry residues (Table 3; data is from 2008). Residue yield from agriculture was estimated at 816 Mt y^{-1}, with a further 368 Mt of forestry residues [19]. The most abundant crop residues are from corn (265 Mt), rice (205 Mt) and wheat (150 Mt) [19]. In addition to cotton stalks, these are also the most commonly used fuels in Chinese biopower plants [33]. These residues do have competing purposes; 500 Mt is available for energy purposes, of which 129 Mt is used for cooking and heating in rural household stoves (2008 data, Table 3). Although the traditional use of biomass remains substantial, total use has decreased by about 60% since 1990 [19,58]. This trend should be expected to continue with the replacement by more modern energy types, and result in more residues being freed up for utilization in biopower projects. The NDRC anticipates strong future growth in manure and MSW production but little growth in crop and forestry residue yield [19].

In 2012, biopower production would have required circa 39 Mt, or 8% of available biomass residues. China's 2020 targets for biopower would require circa 271 Mt, or 54% of all available residues (Table 4).

Table 3 – Crop and forestry residues: quantity and uses.

Category	Amount (Mt)
Total residues	1,184
Crop residues	816
Forestry residues	368
Unavailable for energy purposes	684
Animal feed	211
Stubble left in field	133
Fertilizer/soil improvement	102
Other	31
Forestry residues unavailable for energy purposes	207
Available for energy purposes	500
Unused crop residues	210
Household fuel use[a]	129
Forestry residues	161

[a] Includes biomass briquettes, see also Table 2.
Source: [19].

Despite the relatively low fraction of available residues being used in biopower projects, there are increasing reports of fuel supply problems [16,19,59]. This is likely, at least in part, due to the geographic concentration of biopower projects.

The most abundant residue resources are found in the Northern and North-Eastern provinces, whilst these provinces, until the Feed-In-Tariff reform of 2010, had the lowest biopower prices [58,60]. Projects are currently strongly concentrated in the Eastern provinces (Fig. 7). More importantly, some areas have projects (or planned projects) in close proximity (less than 100 km) to each other, in spite of regulations against such concentration [36] (see also Section 3.1). This will have led to competition over resources available from local agriculture.

It is worth pointing out that organizing of a fuel supply network should be expected to be a challenging task anywhere in rural China. A 30 MW power plant will consume circa 250 kt y^{-1} of crop residue [33]. The average yield of corn, the most abundant residue, is 5.5 t hm^{-2} [61]. Residue (corn stalk) yield is approximately 11 t hm^{-2}, of which ca. 2.8 t hm^{-2} is available for biopower generation ([19]; see also Table 3). The average farm size in China is between 0.5 and 1.0 h m^{-2} per household [61,62]. Further, households in less well developed areas largely use their farmland for crops as needed by the household rather than having a single cash crop. The required network of suppliers should therefore consist of several 10,000s of households, and even several 100,000s of households in less well developed areas.

Table 4 – Crop and forestry residue use for Chinese biopower targets.

	2012	2015	2020
Crop and forestry residue based biomass power			
Capacity (MW)	4,632[a]	8,000	24,000
Production (TWh)	22.3[b]	48[c]	144[c]
Resource use (Mt)[d]	33.4	72	216
Compacted fuels			
Production (Mt)	5	10	50
Resource use (Mt)[e]	5.5	11	55
Total resource use (Mt)	38.9	83	271
Use as share of available	7.8%	16.6%	54.2%

[a] Assuming 1.7 GW bagasse power and 2.9 GW other crop and forestry residue based biomass power (see Section 3.2).
[b] Assuming a capacity factor of 54%, see Fig. 6.
[c] Assuming a capacity factor of 68.5% as targeted by policy [84].
[d] Assuming resource use of 1.5 t MWh^{-1} (average reported in CDM applications [33]).
[e] Resource use as suggested by Ref. [19].

3.5.2. *Fuel cost*

A number of previous studies have reported sharp increases in biomass residue cost with the increased utilization by biomass power projects [16,60,63], and data from CDM applications shows a similar trend (Fig. 8). Data suggests average fuel prices have plateaued around 35 € t^{-1} in recent years, although other reports claim prices of up to 42 € t^{-1} in some regions [16,63,64]. Furthermore, longer term increases in prices remain likely. The price for these resources is determined by the prices paid for competing uses (Table 3), as well as the labor and fuel use for collection and delivery of the resources. The total number of animals kept in China's animal husbandry sectors is rapidly expanding, increasing future feed demand [19]. Cost of the fuel consumed during collection and transport of the biomass resources are also likely to continue to rise. Lastly, with increasing rural economic development, labor cost should be expected to keep increasing as well.

3.5.3. *Heat sales revenue*

The combined generation heat and power (CHP) can significantly increase revenue of a biomass power project. A boiler can supply significant amounts of (waste) heat without significant increases in fuel consumption. CHP is a well-developed form of biopower in the Northern European countries [41,42]. Heat is not easily transported over long distances, however, and therefore needs to be supplied to local district heating networks or industrial processes [41,42].

In China, the average price for the supply of heat is 4.1 € GJ^{-1} (incl. VAT) [33]. There are no government subsidies for heat from biopower. A typical 30 MW biopower project in China supplies circa 750,000 GJ y^{-1} [33]. At those average levels of price and of supply, heat sales can increase revenue by approximately circa 22%. The contribution of heat sales and other sources of revenue for a typical project is presented in Fig. 9.

However, around two-thirds of currently operational projects and an even larger share of planned projects have failed to find demand for heat supply (Fig. 10). Interviewees, as well as many CDM applications indicated that this was due to a lack of existing centralized infrastructure or limited demand for heat and steam [33].

3.5.4. *Carbon credit sales*

Chinese GHG emission reduction projects are eligible for registration as a CDM project and may trade the resulting carbon credits ‘CER’ (certified emission reduction) in international markets. The large majority of Chinese biomass projects has registered or is requesting registration as a CDM project (Fig. 10).

Between 2009 and 2012, CER futures have traded for approximately 12 € t^{-1} CO_2-eq [65], and forecasts have long

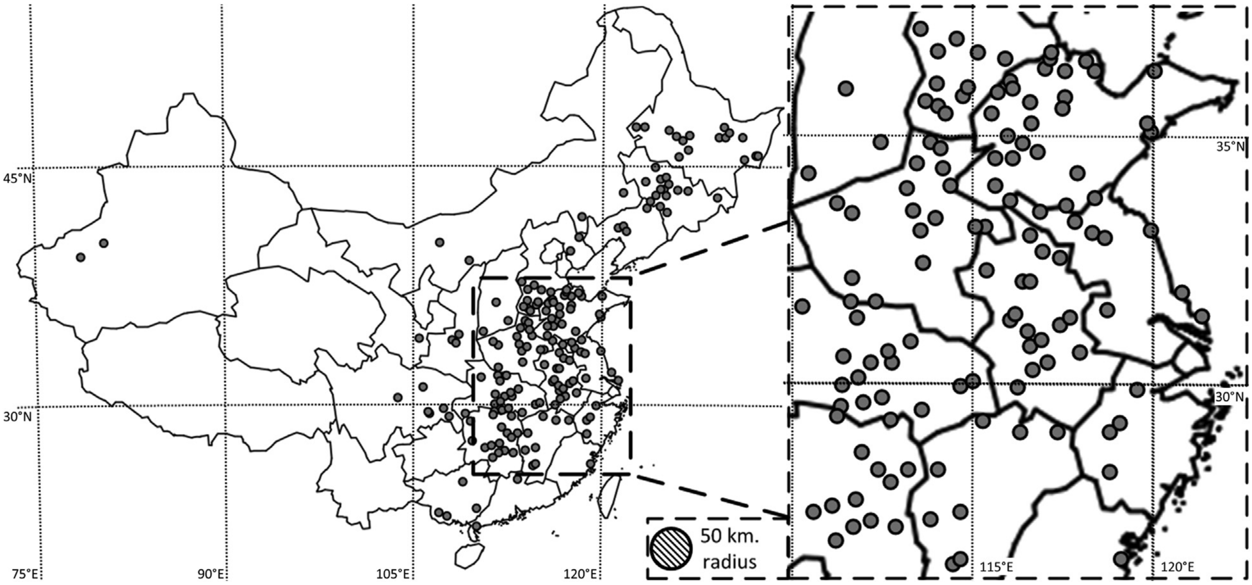

Fig. 7 – Location of biopower projects in China. Notes: includes both operational and planned projects; the 50 km radius is the suggested exclusive resource collection area, see also Section 3.4.1; the 50 km radius is scaled for the blown-up, right hand section of the map. Data source: [33].

suggested stable or rising CER prices over the period until 2020 [65,66]. CDM applications for Chinese biopower projects have assumed a CER value of circa 9 € t^{-1} CO_2-eq on average, which equates to 7.75 € MWh^{-1}. Contribution of CER income to lifetime revenue for a typical biopower project is included in Fig. 9.

Carbon markets in the EU, the largest active carbon trading market, has suffered from strong oversupply, however [67]. To curb supply, the European Parliament has decided that CER from CDM projects registered from Jan. 1st 2013 onwards cannot be exchanged with EUA (European emissions allowance), i.e., cannot be used to offset emission reduction obligations in the EU (with the exception of CER from the 'Least Developed Economies') [68]. Outside of the EU market global CER prices have slumped to as low as 0.30 € t^{-1} CO_2-eq [69],

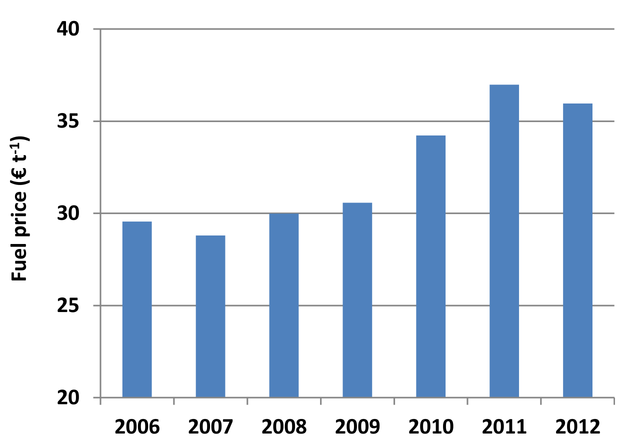

Fig. 8 – Crop and forestry residue prices in China. Note: prices based on wet basis; prices are averages for a variety of different residues; VAT incl. Data source: [33].

with little expectation of strong improvement in the period until 2020 [69,70]. This has strongly impacted Chinese CDM applications. In both 2011 and 2012, around 1000 Chinese CDM applications were submitted (all project types); in 2013, only 43 new applications were submitted [71]. China is currently piloting domestic trading schemes for carbon emissions, but national coverage and strongly increased demand may be many years away [72].

3.6. *Investment outlook: NPV and minimum feed-in-tariff needed to spur investment*

Here, results from Sections 3.1–3.5 are combined to calculate the current Net Present Value of new biomass power projects, as well as the minimum level of Feed-In-Tariff required to keep NPV positive.

3.6.1. *Net Present Value of new investment in biomass power*

A discounted cash flow model for a typical biomass power project was made, against an internal rate of return of 8%. The values used for the main financial and operational parameters in the estimation of this Net Present Value (NPV) have been derived in Sections 3.1–3.5, but a summary overview is provided in Appendix A. A number of parameters included in this full list in Appendix A have not been dealt with in detail in Sections 3.1–3.5. These have been derived from project files as included in the project database (included in the Supplementary material). The estimation of NPV includes a range of values for fuel price, capacity factor, and whether or not the projects' developers manage to find demand for the supply of heat and/or carbon credits (Fig. 11).

It appears that either the supply of heat or carbon credits is sufficient to keep project NPV above zero over the entire range of fuel prices used. However, with the current lack of demand

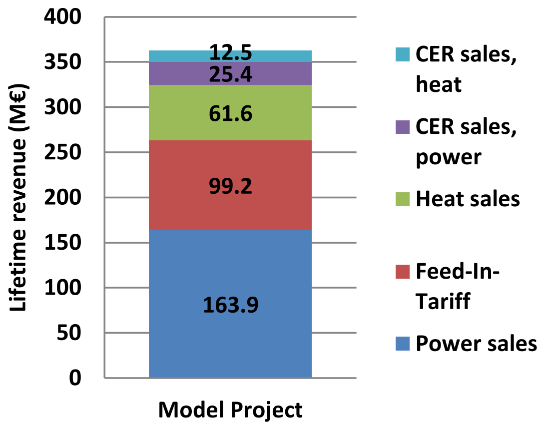

Fig. 9 – Lifetime revenue of a typical biopower project, by revenue source. Notes: revenue incl. VAT; assumptions: see Appendix A.

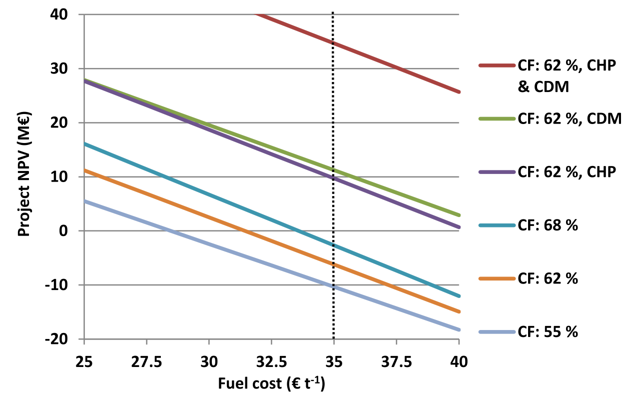

Fig. 11 – NPV of a model biopower project in China. Notes: CF: Capacity Factor; CHP: project sells heat and power; CDM: project supplies CER; assumptions: see Appendix A; dashed line is approximate current fuel cost (see also Fig. 8).

for carbon credits from China, and with difficulties for most projects to find demand for heat supply, it is the bottom three lines in Fig. 11 that are most relevant. At a capacity factor of 55% (average of all operational plants), 62% (as assumed in CDM applications), and even at a high capacity factor of 68% (as targeted by policy), the NPV is below zero at current biomass fuel prices (Fig. 11).

This estimated lack of attractiveness of current investment in biomass power projects is not merely a theoretical issue. These problems already appear to have had an effect on biopower plant operators and development plans. Kaidi reported a gross profit of 11.0 M€ for its biomass arm over 2011, but a gross loss of 4.6 M€ in 2012, despite an increase in the number of operational plants [25]. From 2011 through 2013, Kaidi completed construction on 19 biopower plants [26]. Kaidi initially had plans for at least another 26 more plants [33], but has not started construction on a single new project between March 2012 and March 2014 [26,73]. Unfortunately, NBE is not publicly traded and therefore does not publish publicly available annual reports. The amount of 'planned' projects reported in Fig. 1, however, likely contain a large share of projects that have been canceled and this number is therefore over-optimistic, in particular seen Kaidi's share in future development plans (Fig. 2).

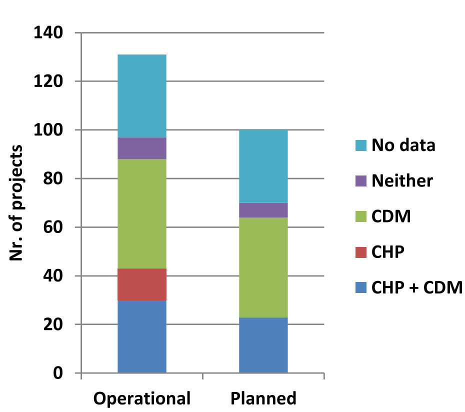

Fig. 10 – Nr. of biopower projects supplying heat or CDM credits. Source: [33].

3.6.2. *Minimum feed-in-tariff required to spur biomass power investment*

Using the same NPV model, the minimum Feed-in-Tariff (FIT) required to keep project NPV positive was calculated. As can be deduced from results in Fig. 11, the current FIT of 90.9 € MWh^{-1} is sufficient for projects that manage to derive revenue from sales of either heat or CER, within the entire range of expected values for capacity factor and fuel prices. In the most likely scenario that no revenue from these sources can be secured, the FIT needs to be at least 97 to 105 € MWh^{-1} to keep NPV positive, depending on capacity factor and fuel price (Fig. 12).

4. Discussion and policy recommendations

The accuracy of the Net Present Value of biomass power projects in China, as reported in this study is mostly

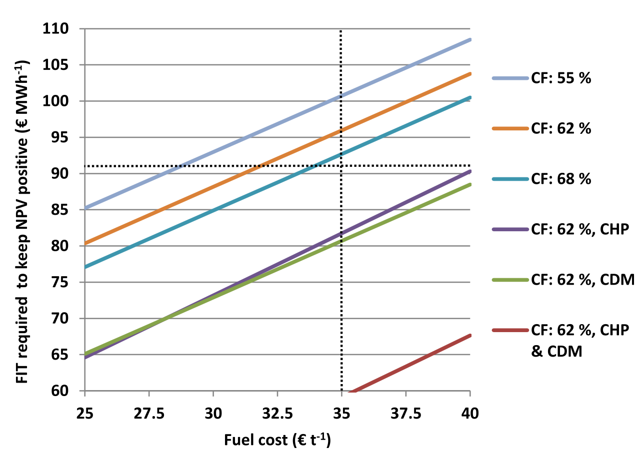

Fig. 12 – FIT at which model biopower project NPV equals zero. Notes: CF: Capacity Factor; CHP: project sells heat and power; CDM: project supplies CER; assumptions: see Appendix A; dashed line indicate current FIT level and approximate current fuel cost (see also Fig. 8).

dependent on the estimates of the following parameters: construction cost, fuel price, capacity factor, revenue from carbon credit and heat sales.

The estimates of construction and fuel cost are derived as averages from a large number of publicly available and externally audited project files (the CDM registry; [22]). The estimated construction cost of 1150 € kW^{-1} is in line with values reported by earlier work. A number of earlier studies have suggested 1100 to 1300 € kW^{-1} for foreign technology versus 785 to 910 € kW^{-1} for domestic technology [17,18,64,74,75]. Although a small number of projects in the overview presented in Fig. 5 do indeed report values as low as 750 to 900 € kW^{-1}, there is a clear convergence towards the 1150 € kW^{-1} mark, for projects using either domestic or foreign technology.

Estimates on fuel cost are entirely in line with earlier reports. Estimates have suggested costs of as low as 18 to 24 € t^{-1} prior to circa 2010 [18,76], but there is general consensus that prices have risen to around 35 € t^{-1} or even higher in recent years [75–77]. Zhao and Yan do note that price differences remain between China's regions, of between 27 and 42 € t^{-1} [64].

The capacity factors used in this report are derived from government reports on payments to individual projects, and there is little reason to assume these would be underreported.

Data is also consistent with reports by a recipient of the subsidies, Wuhan Kaidi [24]. Although a number of earlier studies have indicated problems with poor technological performance, these have not reported the extent of these problems in an estimate of availability or capacity factor [59,76].

The current problems with securing additional revenue via sales of carbon emissions permits or through the sales of heat have been discussed in Sections 3.5.3 and 3.5.4. As the assumption in our estimate is that no revenue is obtained from these sources, this requires little further comparison with estimates from earlier reports.

Lastly, in the estimates of NPV and required Feed-In-Tariff, scenarios have further incorporated a range of fuel prices and capacity factors, which cover the low to high end of estimates on the value of these parameters as reported in this study, as well as earlier reports.

Taken together, and assuming a minimum internal rate of return of 8%, investors would want to see revenue of between 97 and 105 € MWh^{-1} before investing in biopower projects. Liu and colleagues [17] reported a rough estimate of 54–108 € MWh^{-1} in a study that compared several renewable energy technologies. Zhao and colleagues reported a single estimate of 79 € MWh^{-1} [16], and Mang reports a range of 85–97 € MWh^{-1} [77]. These estimates should be somewhat lower than those made in this study, as these studies all reported pure generation costs, i.e., at zero profit. It is not immediately clear what levels of fuel cost and/or capacity factors were used in deriving these estimates and further comments on comparability is therefore difficult.

The simplest policy solution to ensure reasonable profitability in the sector, then, would be to increase the Feed-In-Tariff, from the current 91 € MWh^{-1}, to levels of between 97 and 105 € MWh^{-1}. In national currency this equates to 800 to 865 CNY MWh^{-1}, up from the current level of 750 CNY MWh^{-1}.

Instead of an increased FIT, profit levels may also be improved through exceptions in corporate income tax or VAT. Such exceptions, and their extent, may be made conditional on fuel prices and/or whether or not individual projects manage to secure revenue from heat sales. Such a conditional system would be better organized via income tax or VAT because this requires sufficient insight into individual projects finances. The Ministry of Finance and its State Administration of Taxation can be expected to have such insight, whereas grid operators, which currently distribute the FIT payments, may not.

Governmental organizations may also help encourage heat utilization. Local governments may have a key role in organizing heat demand from biomass power projects in local industrial parks or residential heating networks. This, too, may also require a financial incentive, e.g., canceling VAT over heat from renewable resources.

There is also a need for more dependable fuel supply networks. Local rural energy bureaus may be the most suited organization to assist operators with this task, as they have well developed relationships with local farming communities for a variety of other government programmes. Experiences and best practices in doing so could be disseminated via provincial or national networks of local bureaus.

Functional fuel supply networks are most needed in the vicinity of biopower projects, but could also be set up in areas more remote from biomass power projects. Fuel collection stations could collect crop wastes and process these into briquettes or pellets, to be used locally, in household stoves, or transported to more remote fuel markets. Networks of collection station could grow out to provincial or national levels, and even be integrated with international markets for pelletized fuels. Such a supply network can help mitigate seasonal or local fuel shortages and price fluctuations, reducing supply risks for biopower plan operators.

5. Conclusion

Chinese policy ambitions to develop biopower have been successful to a certain extent. The establishment of a Feed-In-Tariff, combined with a number of ambitious project developers, has ensured relatively rapid growth of the pathway of direct firing of crop and forestry residues. Installations have grown to circa 1 GW of annual additions, and an increasing number of project developers and boiler manufacturers have entered the market.

In order to continue to promote investment in the sector, however, Feed-In-Tariffs should be increased to levels of between 97 and 105 € MWh^{-1}, so that future investments remain reasonably profitable. A number of developments have affected the investment outlook for biopower projects, and without an increased FIT, growth should be expected to stall. Fuel prices have rapidly risen, local competition over biomass resources appears to be affecting fuel availability, operational performance of power plants has remained behind on expectations, and carbon markets are no longer providing a much needed additional source of revenue. It is entirely unlikely that these parameters will improve within the foreseeable future. No significant further reductions in construction costs are to be expected, neither global nor domestic carbon markets are going to improve significantly within the next few years, and fuel prices are more likely to rise than to fall.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.biombioe.2014.12.014.

Appendix B. Main parameter assumptions for NPV calculation of a model biopower project

Parameter	Value	Unit
General		
Installed capacity	30	MW
Capacity factor	62.4	%
Net power generation	163,987	MWh yr^{-1}
Heat supply (if CHP)	750,000	GJ yr^{-1}
Technical lifetime	20	yr
Revenue		
Electricity tariff, years 1–15, VAT incl.	90.9	€ MWh^{-1}
Electricity tariff, years 16–20, VAT incl.	50.3	€ MWh^{-1}
Heat price, VAT incl.	4.1	€ GJ^{-1}
Investment		
Construction cost	1,150	€ kW^{-1}
Static total investment	35,500,000	€
Construction interest	1,104,000	€
Discount rate	8	%
O&M		
Fuel consumption (pure electric)	1.50	t MWh^{-1}
Fuel consumption (CHP)	1.65	t MWh^{-1}
Water and other material cost	275,000	€ yr^{-1}
Maintenance (2.5% of investment)	845,595	€ yr^{-1}
Staff	525,000	€ yr^{-1}
Other	350,000	€ yr^{-1}
Taxes		
VAT: electricity, CER, equipment, maintenance	17	%
VAT: heat, biomass fuel, water	13	%
Income tax, yrs 1–3	0	%
Income tax, yrs 4–6	12.5	%
Income tax, yrs 7–20	25	%
CER		
CER price, VAT incl.	9	€ t^{-1}
Exchange rate €: CNY	8.25	n/a
Grid emission factor electricity (CO_2-eq)	0.893	t MWh^{-1}
Grid emission factor heat (CO_2-eq)	0.0955	t GJ^{-1}
Crediting period	3 × 7	yr

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