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Identifying a role for biomass gasification in rural electrification in developing countries: the economic perspective

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Abstract

The potential of biomass gasification for the electrification of rural areas in developing countries is investigated, both technology oriented (the prospects for the technology) and user oriented (is the technology feasible for the situation?). The analysis is carried out by means of an annuity costing model, taking proper account of the time value of money. Care has been taken to create an equal basis of the differences in technical lifetime of certain components of the technical systems evaluated. The evaluation method distinguishes two types of parameters: technology parameters and site parameters. The analysis tool thus provided yields discriminating conclusions about the feasibility of biomass gasification under different circumstances. Part of the technology parameters is a coherent costing model provided here. The site parameters include prevailing fuel prices, which are provided for a number of potential target countries. The capacity range considered is covered by an investigation of three cases (10, 40 and 160 kW). Mass production of gasifier systems is identified as a prerequisite for further utilization of the technique in rural electrification. Target cost levels are indicated on the basis of allowable investment in view of applicable discount rates and equipment utilization rates under typical rural electrification circumstances. The evaluation methodology developed is also proposed as an assessment tool for quick scans of project feasibility.

Keywords: Gasification; Rural energy; Energy planning; Economics; Biomass

1. The problem

The provision of electricity to households in the rural areas of developing countries is an objective which has been recognized by governments of these countries as well as by donor agencies and international financing institutions. This paper addresses the potential of some technical means which are being employed or may be employed for rural electrification. Rural electrification is characterized by:

- the areas are remotely located from large-scale electricity grids;
- the electricity consumption shows a need for the installation of small power capacities; [1]

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[1] "Power capacity" is defined in Appendix A.

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- the electricity consumption pattern necessitates the operation of installed power capacities at low capacity factors,[2] which means that the installed capacity (and hence the capital invested) is used much less intensive than in the case of medium- and large-scale power plant.

In addition to the extension of existing electricity grids there are at least the following technical options capable of coping with these technical and economic conditions:

- to create a small isolated grid, powered by a small-scale generator;
- to provide individual households with batteries, charged at a central station which is powered by a small-scale generator;
- to provide individual households with their own solar-powered home system.

This paper does not consider the latter option, but is about the type of small-scale generators employable in the first two options. Typical scales for these small power generating plant are 10–200 kW.

The particular question investigated here, is under which economic conditions biomass gasification can play a role in these small power generating plant. Biomass gasification, as opposed to fossil fuel driven generators, has the advantage that biomass fuels may be produced locally and therefore cheaper than fossil fuels. A further reason for considering biomass gasification is its potential to be exploited in a sustainable manner in view of greenhouse gas emissions.[3] The question of the potential role of biomass gasification was approached from two directions:

1. *Technology oriented*: Given common economic conditions and the state of the art of the gasification technology, what is the perspective of the biomass gasification technology? What will be the influence of changing economic conditions? Is there a perspective for advanced developments in biomass gasification technology?
2. *User oriented*: Given location specific economic conditions and the state of the art of the gasification technology, do these local conditions favour biomass gasification?

[2] "Capacity factor" is defined in Appendix A.

[3] The cycle of CO_2 capture and emission is closed if the biomass utilized is grown at the same rate.

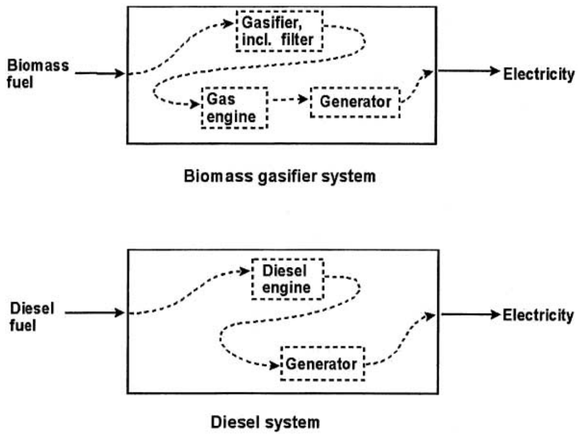

Fig. 1. The power systems considered.

Whereas the first approach is of relevance to those who determine R&D strategies, the latter concerns the questions usually addressed by potential users of biomass gasification technology.

The role of biomass gasification is not a matter of economy alone. There are a number of other issues determining its potential. Economic feasibility is just one of the conditions. However, as a condition it needs a particular analysis — the issue on which the present paper is focused.

2. Methodology

Within the framework of small-scale power generation, the obvious alternative to biomass gasification is to utilize diesel fuel in an internal combustion engine which powers an electricity generator. The biomass gasification system would consist of a gasifier with gas filter, an internal combustion engine as well as an electricity generator. The two systems are illustrated in Fig. 1.

The differences between the diesel and the gasification options are mainly characterized by the investment and operating cost (Table 1). Hence the choice between the two options is a customary investment decision. The tools to evaluate such decisions are strongly developed enabling a subtle and differentiated foundation. The aim of this paper however is to draw general conclusions and to develop generally applicable tools — tailored to deriving rules of thumb. Therefore the following is not considered: the role of

Table 1
Approximate characterization of diesel and biomass gasification alternatives

	Biomass gasification system	Diesel system
Investment	High	Low
Operating cost	Often low	Often high

inflation, profit taxes, loan gearing and project development cost. Further, the nature of the technologies considered is such that pluri-annual start-up does not play a role. In view of the objectives of this paper, therefore, an annuity method for capital cost determination may suffice.

The parameters determining the economic feasibility of biomass gasification for rural electrification can be distinguished into those determined by the location where (and the user by whom) the technology may be employed (the site parameters) and those determined by the technology (the technology parameters). The technology parameters are:

- the size of the investment;
- the technical lifetime of system components;
- energy conversion efficiency and calorific values of the fuels;
- operator cost;
- consumables utilization (cost); and
- maintenance cost.

These technology parameters may be different for various power capacity scales, and perhaps even for various countries or regions, but once they have been established the feasibility of biomass gasification depends on the following site parameters:

- the discount rate;
- the capacity factor;
- the biomass fuel price; and
- the diesel fuel price.

The discount rate is a matter of the enterprise considering the investment. Utilities usually assume a discount rate of 10–15% [1], depending on the particular economic conditions under which they operate. A private enterprise on the other hand may set its discount rate at 30% or higher. Also the capacity factor is location specific. It is strongly determined by the presence of local industries and commercial services or hospitals. In their absence the electricity consumption is limited to household use only, thus lowering the achievable capacity factor. Finally, in developing countries, fuel prices are different from one country to another and one region to another. This particularly applies to biomass fuels, but transport distances may also result in a variety of prices for fossil fuels within one country.

Table 2
The calculation model[a]

Cost item	Production cost (€/kWh)		
	Biomass gasifier system	Diesel genset	Incremental cost
Capital cost (annuity)			
Gasifier	R		R
Gas engine	GasE		GasE
Diesel engine		DE	−DE
Generator	Gen	Gen	0
Hand factors	H		H
Working capital	x	x	0
Operational cost			
Operator	x	x	0
Biomass	BF		BF
Diesel fuel		DF	−DF
Lubricants	LB	LD	LB-LD
Maintenance	MB	MD	MB-MD
Total cost	TB	TD	TI

[a]x: Neglect (cost are assumed equal for the two options).

The calculation model developed for the analysis is built-up as shown in Table 2. The symbols in this table have the following meaning:

R	annuity of the gasifier investment (R: reactor)
GasE	annuity of the gas engine (GasE: gas engine)
DE	annuity of the diesel engine (DE: diesel engine)
Gen	annuity of the electricity generator (Gen: generator)
H	annuity of the Hand factors for piping, isolation, electrical wiring, instrumentation, controls, software and assembly
BF	the cost of biomass fuel
DF	the cost of diesel fuel
LB	the cost of lubricants used for the biomass gasifier system

LD the cost of lubricants used for the diesel system
MB maintenance cost applicable to the biomass gasifier system
MD maintenance cost applicable to the diesel system

TB and TD are the respective total production costs. TI is the incremental production cost of electricity produced with the gasifier system relative to the diesel system. All these costs are expressed on a product basis (€/kWh).

2.1. Completing the model with data

For the determination of capital cost a project duration of 10 yr was assumed. The value of the investments at the end of year 10 was assumed to be zero. Generally, the depreciation period was set equal to the project duration. However, the technical lifetime of some of the system components may be shorter than the project duration. In that case reinvestment is required and, accordingly, the depreciation period was set at the applicable technical calender lifetime. Capital cost items could be extended further by the interest cost of working capital. However, the nature of the projects considered is such that those costs may be neglected in the comparison. The same applies to the cost of the required operators — they are assumed to cancel out in the comparison. Major operational cost items are fuel and lubricants. Fuel costs are determined by energy conversion efficiency as well as by the specific fuel prices (€ per litre or tonne).

2.2. Elaboration and interpretation

If the resulting incremental costs (€/kWh) are zero or negative, the additional capital invested in the gasifier project yields a return rate which is equal or higher than the discount rate. [4] Hence, the biomass gasification option is economically feasible. Whether or not this is the case depends in the following manner on the site parameters:

[4] The discount rate is interpreted here as the minimum rate at which an investor is willing to invest his capital. Note that it is not needed to draw up cash flow schedules for properly taking into account the time value of money. The annuity method serves the same purpose.

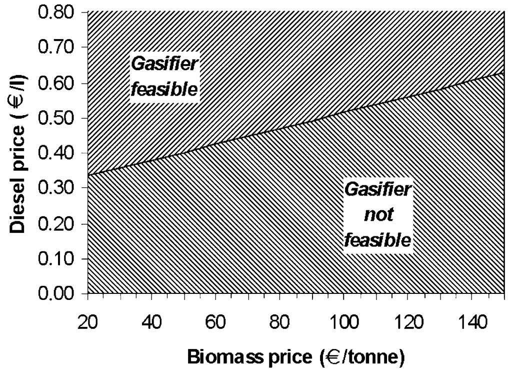

Fig. 2. Example of a graph representing a line of equal production cost (drawn for two fixed site parameters: discount rate, capacity factor). The data shown do not generally apply.

- *Discount rate*: Due to the relative differences in capital involvement for the two options, a low discount rate favours the biomass gasification option.
- *Capacity factor*: The capacity factor may influence unit production cost in two opposite directions. The negative feed-back of the more intensive capital utilization (lower production cost) may be off-set by decreased depreciation periods for those capital goods which have a shorter technical lifetime than the project duration. The influence of the capacity factor is strongest for the more capital intensive alternative (biomass gasification).
- *Biomass fuel price and diesel fuel price*: By immediately affecting the operating costs, the total incremental cost of the biomass gasifier system increase (decrease) with increasing biomass fuel price (diesel fuel price).

The calculation algorithm is further elaborated by deriving sets of site parameters under which the incremental costs for the biomass gasifier system are equal to zero. Where these sets apply in reality, the biomass and diesel alternatives are equally attractive. Elsewhere there is an economic preference for one of the two. The sets of site parameters are reproduced in two-dimensional diagrams, one type of which is illustrated in Fig. 2. Since, as defined above, there are four independent site parameters, there are six two-dimensional diagrams indicating conditions of equal costs. The graphs produced are used to address the questions raised above.

The graphs are produced using a spread-sheet computer program employing the "tables" or "what–if" functions to calculate the break-even fuel prices. [5] Suitable equations for those prices are, for the break-even diesel price:

$$\text{break-even diesel fuel price} = \text{diesel fuel price}(1 + \text{TI}/\text{DF}),$$

where the diesel fuel price is the price with which TI and DF have been determined, according to the calculation procedure explained above. This means that the diesel fuel price is also implicitly present in the two parameters TI and DF. This is a relevant remark since the equation given suggests, erroneously, that the break-even diesel price would be directly proportional to the diesel price. In fact it is independent of that price. For the break-even biomass price the following equation applies:

$$\text{break-even biomass price} = \text{biomass price}(1 - \text{TI}/\text{BF}).$$

Again, the fuel price (here the biomass fuel price) is also implicitly present in the other two parameters (here TI and BF) such that the fuel price is independent. Certainly the concept of break-even diesel price is not new for feasibility analysis (see e.g. [2]). The novelty in the approach is that in the present study this break-even price is not the intended final analysis result, but rather an interim calculation result by means of which multi-dimensional break-even conditions are determined.

Finally, two remarks should be made about the type of economic evaluation carried out here. (1) The analysis is on the project level from the viewpoint of the private investor. Hence market prices rather than border prices or shadow prices are used. (2) With the development of the so-called flexible tools (Joint Implementation, Clean Development Mechanism, emission trade) avoided greenhouse gas emissions can be valued in monetary terms and made payable to the private investor in a project. The effects of this particular type of internalisation are investigated in Section 5.3 of this paper.

[5] A break-even fuel price is the calculated value of fuel which would precisely result in equal production cost for the biomass and diesel option. It can be determined for either diesel or biomass fuel (ceteris paribus).

3. Elaboration for three typical power capacities

The power capacities concerned with rural electrification — in as far as the feeding of isolated grids or of battery charging stations is concerned — range from 10 to about 200 kW. In this investigation three cases, representing typical capacities for which distinctive economies of scale may be expected to apply (i.e. 10, 40 and 160 kW) were examined. For the 10 kW system, the fuel for the biomass gasifier system is charcoal. For 40 kW either wood or charcoal applies and for 160 kW wood was assumed.

3.1. The technology parameters

3.1.1. Investments

Biomass gasifiers are offered by a small number of manufacturers. Fourteen were reported by Reed and Gaur [3] of which only a few are able to guarantee the performance of their equipment, mainly due to lack of experience. A cost analysis of systems offered to date is not necessarily sufficient to carry out investigations aimed at drawing conclusions about the future of the biomass gasification technology. Therefore, to develop an *understanding* of the cost break-down of the investments is as important, if not more so. Nevertheless, it makes sense to review investment costs which appear in current and past markets.

On the basis of the "small-scale biomass gasifier monitoring programme" [6] carried out by UNDP and the World Bank, Stassen [2] reports the investment data reviewed in Table 3 (see also [4]). The programme was carried out between 1983 and 1990. The gasifiers monitored originated from a number of countries. Bridgwater [5] reviewed the investment cost for a range of capacities which are essentially larger (i.e. 0.1–10 MW) than the capacities investigated here. His analysis is therefore not immediately suitable for this study.

In this analysis cost estimates presented in Table 4 were used. They apply to turn-key gasifier systems, ex-manufacturer. Thus transportation costs are excluded. Neither has a start-up and training component been included. This does not imply that those costs would be negligible. They are to be included

[6] Gasifier systems monitored were located in Indonesia, the Philippines, Brazil, Vanuatu, Mali, Seychelles and Burundi.

Table 3
Investment cost for monitored gasifier systems (US$/kW), after Stassen [2]

Cost item	Capacity (kW) and fuel		
	10, charcoal	30, wood	100, wood
Gasifier incl. filter and gas cooler	217–1001	225–1035	159–880
Gas engine	466	300	185
Generator, incl. electrical controls	402	259	160
Total	1085–1869	784–1594	504–1225

Table 4
Gasifier system investment cost used in this study (€/kW)

Cost item	Capacity (kW) and fuel						
	10		40			160	
	Charcoal	Diesel	Charcoal	Wood	Diesel	Wood	Diesel
Basic equipment (BE)							
Gasifier							
Fuel preparation	—	—	—	—	—	300	—
Fuel storage	—	—	—	—	—	300	—
Fuel feeder	—	—	—	—	—	300	—
Reactor	460	—	264	660	—	500	—
Dust filter	100	—	60	240	—	180	—
Tar filter	—	—	—	0	—	0	—
Gas cooler	0	—	0	0	—	0	—
Gas engine	370	—	160	160	—	70	—
Diesel engine	—	300	—	—	120	—	50
Generator	420	420	180	180	180	80	80
Total basic equipment	1300	720	714	1290	300	1800	130
Hand factors							
Piping, isolation	26	—	14	26	—	36	—
Electrical wiring	0	—	0	0	—	54	—
Instrumentation	0	—	0	0	—	108	—
Controls, software	0	—	0	0	—	108	—
Assembly	65	—	36	64	—	18	—
Transport to site	0	0	0	0	0	0	0
Erection on site	0	0	0	0	0	0	0
Training	0	0	0	0	0	0	0
Production start-up	0	0	0	0	0	0	0
Insurance	0	0	0	0	0	0	0
Total investment	1391	720	764	1380	300	2124	130
Hand factors as % of BE							
Piping, isolation	2%	—	2%	2%	—	2%	—
Electrical wiring	0%	—	0%	0%	—	3%	—
Instrumentation	0%	—	0%	0%	—	6%	—
Controls, software	0%	—	0%	0%	—	6%	—
Assembly	5%	—	5%	5%	—	1%	—

in a further refinement. The cost analysis given in Table 4 is an attempt to create coherence between the cost estimation of different gasifier systems and their alternative (diesel gensets). The system components necessary in the various systems are distinguished. For each component, generally, use is made of scale factors in the range of 0.4–0.7, depending on the type of component. It is shown that in the smaller

Table 5
Technology parameter values for the various cases

General technology parameter values				
Net calorific value, wet basis (GJ/t)				
Charcoal	28			
Wood	14			
Diesel fuel	43			
Density diesel fuel (t/m^3)	0.70			
Case-specific technology parameter values	Capacity (kW) and fuel			
	10	40		160
	Charcoal	Charcoal	Wood	Wood
Energy conversion efficiency (% on NCV_w)				
Biomass gasifier system	12.5%	16%	16%	22%
Fossil-fuelled alternative	30%	30%	30%	35%
Maintenance (% of equipment/8000 full-load equivalent hours)				
Biomass gasifier system	15%	15%	15%	15%
Fossil-fuelled alternative	5%	5%	5%	5%
Lubrication (€/kWh)				
Biomass gasifier system	0.02	0.02	0.02	0.02
Fossil-fuelled alternative	0.005	0.005	0.005	0.005

gasifier systems mechanised fuel preparation, storage and feeding units are not required. Charcoal gasification reactors are substantially cheaper than wood gasification reactors, due to the more complicated construction of the latter. Engine derating (which occurs when petrol engines are converted to gaseous fuels) results in essentially higher costs for gas engines in comparison with diesel engines. In the end, all components are to be integrated into one system. The associated costs are reflected in the Hand factors. It is shown that in the larger gasification system substantially higher integration costs are involved. The prices fit reasonably well within the ranges given by Stassen [2], particularly at the lower capacity range. For the higher capacity, prices have been verified with the firm Kara Energy Systems [6].

3.1.2. Technical lifetimes

Information on technical lifetimes of the various system components is not available. Hence estimates had to be made. Whereas it is reasonable to suppose that gasifiers can be easily made for a technical lifetime which is equal to the project duration, this does not apply to every candidate gas engine. The technical lifetime of a mass-produced retrofitted petrol engine (in the 10 kW range) is 2000 full-load equivalent hours [7]. Other engines which might be employed are second-hand overhauled and retrofitted car engines. Those engines prior to their overhaul for a gasifier project have had a technical lifetime of about 3000 full-load equivalent hours. In a gasifier project, the engines would be utilized under considerably less stressful conditions. It is probably reasonable to suppose another 5000 full-load equivalent hours during the gasifier project. Yet, prior to entering in such differentiated approaches, just new gas engines, sturdy enough to serve a lifespan of 30,000 full-load equivalent hours, were assumed. The same is assumed for the generators.

3.1.3. Other technology parameters

Energy conversion efficiencies and the calorific values of the fuels are reviewed in Table 5, along with consumables and maintenance cost.

3.2. Three site parameters: capacity factor, biomass prices and diesel fuel prices

In this section capacity factor, biomass and diesel fuel prices are considered. Meunier [8] reports

Table 6
Capacity factors for various modalities of rural electrification

Option for use of isolated grid	Unit	Households only	Households plus commercial or industrial services	Households plus battery charging service
Parameter values				
Operational period (OP)	week/yr	52	52	52
	d/week	7	6	6
	h/d	4	24	24
Planned maintenance during OP (PM)	% of OP	0%	10%	10%
Availability factor during (100%−PM)OP	% of (100%−PM)OP	90%	90%	90%
Load factor		50%	50%	80%
Calculated values				
Capacity factor (CF)		7%	35%	55%
On stream time (OST)	h/yr	1310	6065	6065
Fullload equivalent hours	FLE h/yr	655	3033	4852

capacity factors between 6 and 50% (where the 50% is exceptionally high due to the application of street lighting), achieved with rural electrification in five Asian countries. [7] For achievable capacity factors typical conditions of rural electrification (Table 6) were analysed. If only households are provided with electricity, a capacity of 7% appears to be achievable. Higher values may be realized if additional applications are found. If commercial or industrial activities are served as well, the capacity factor may reach a value of 35%. If a battery charging service could be provided with electricity from the generating system, a capacity factor as high as 55% is achievable. In that case battery charging should be continued over night. Note that the systems considered here consist of one single generator set. Under some circumstances it may be advisable to install an additional diesel engine for peak load provision and back-up. The load factor of the gasifier system could then be increased. In the case of the second application of Table 8 (households plus commercial or industrial services), e.g. from 50 to 90%; capacity factor would increase from 35 to 60%.

Diesel fuel prices used were financial prices only, i.e. the prices as they are observed by the end user: including taxes and subsidies. In 1998, the average diesel fuel price in Sub-Saharan Africa was 0.4 US$/l (The World Bank, Transport Division and International Energy Agency, 1998). The maximum price was found in Burundi (0.8 US$/l), the lowest in Zimbabwe (0.2 US$/l). For Asia and the Pacific region, the World Bank Transport Division reports a substantially lower average of 0.2 US$/l, [8] a maximum of 0.3 US$/l (Bangladesh) and a minimum of 0.04 US$/l (Indonesia). The Americas show an average of 0.4 US$/l, a maximum of 0.6 US$/l (Grenada) and a minimum of 0.20 US$/l (Ecuador). It is interesting to compare these data with a pricing model reported by Berg et al. [9] (see e.g. the diesel price reported in Table 7). Levies and taxes are a substantial cost component of diesel fuel prices as observed by end users. They are different for various countries and for various applications. Levies and taxes imposed on diesel fuel intended for commercial non-transport purposes are often lower than those charged on transport fuels. In Table 7 the ex-factory diesel price calculated for a large refinery is reported. This gives a fair indication of lowest non-subsidised diesel cost excluding levies, taxes and transport cost.

Public databases with more or less complete reviews of biomass fuel prices do not exist. A number of reports published by the World Bank, governments and the FAO provide some details on these prices but they are not available in a systematic manner. Wood is a rural fuel, and hence consumer prices are a good

[7] Bangladesh, India, Pakistan, Philippines and Thailand.

[8] Of the listing provided by the World Bank, we take account of developing countries only.

Table 7
Typical fuel prices in selected developing countries

Country	Charcoal[a]		Wood[a]		Diesel fuel	
	€/t	€/GJ	€/t	€/GJ	€/t	€/GJ
Ghana						
Production zone	60	2.11	15	1.05	0.33	5.37
Accra	120	4.21	30	2.10	0.33	5.37
Indonesia	93	3.30	16	1.12	0.043	0.69
Mali	85	2.99	27	1.86	0.122	3.38
Vanuatu-Tanna	146	5.12	37	2.8	0.63	10.2
Diesel fuel ex-refinery (Rotterdam)[b]					0.17	3.07

[a]Estimated by the author, based on Ahiataku-Togobo [10], Meuleman [11] and Sanogo [12].
[b]At crude oil price of 18 US$/barrel, 1US$ = 0.90€. Calculated according to Berg et al. [9].

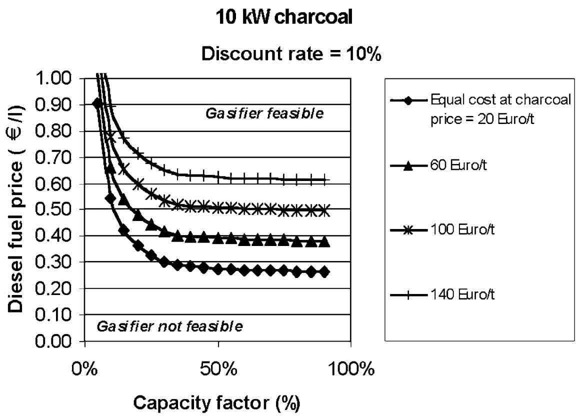

Fig. 3. 10 kW charcoal: Equal cost lines (comparing charcoal gasification and diesel fuelling) for varying capacity factors and diesel fuel prices calculated at a discount rate of 10%.

indicator for the study. This is different for charcoal, which, although produced in the rural areas, is a fuel for application in urban settlements. Biomass fuel prices for Ghana, Indonesia, Mali and Vanuatu are given in Table 7.

4. Calculation results

The results of the model calculations are presented in a number of graphs (Figs. 3–14) for the three capacity scales. The graphs show that capacity factors below 30% strongly determine the economic feasibility of the gasification options. Above a value of 30%, capacity factors are of little influence. Two extremes are therefore used (i.e. a capacity factor of 10 and 50%) to underpin the conclusions.

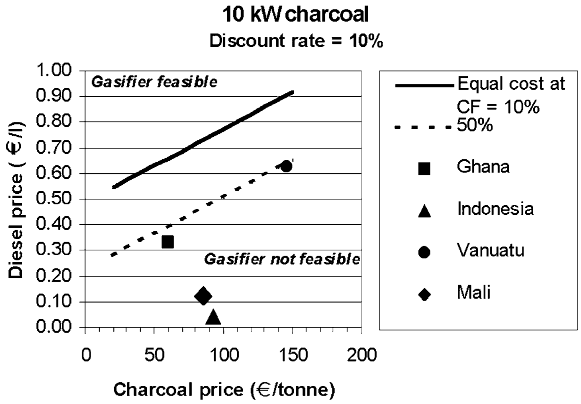

Fig. 4. 10 kW charcoal gasification: Equal cost lines (comparing charcoal gasification and diesel fuelling) for varying fuel prices calculated at a discount rate of 10%.

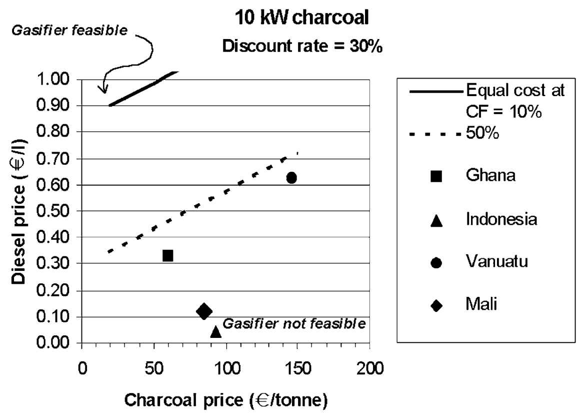

Fig. 5. 10 kW charcoal gasification: Equal cost lines (comparing charcoal gasification and diesel fuelling) for varying fuel prices calculated at a discount rate of 30%.

5. Interpretation

5.1. Preliminary assessment

The conditions under which biomass gasification would become economically feasible are discussed below.

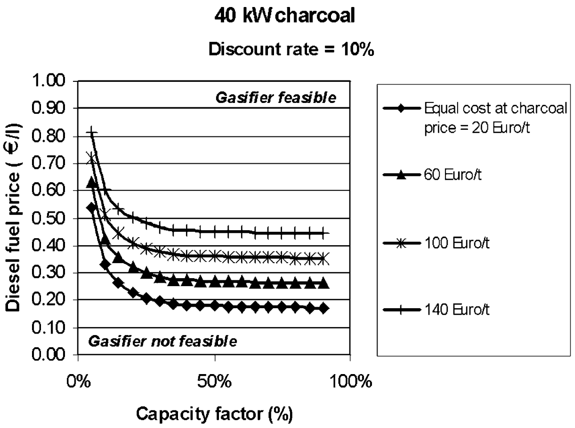

Fig. 6. 40 kW charcoal: Equal cost lines (comparing charcoal gasification and diesel fuelling) for varying capacity factors and diesel fuel prices calculated at a discount rate of 10%.

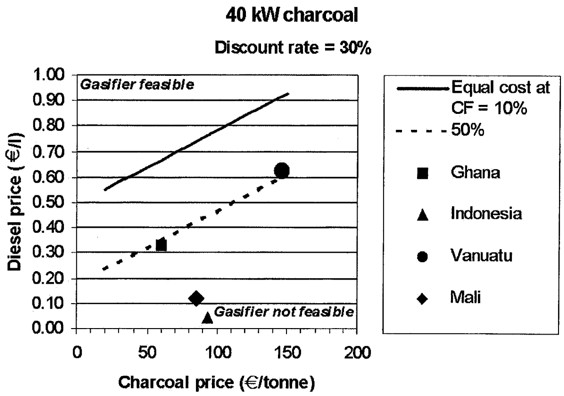

Fig. 8. 40 kW charcoal gasification: Equal cost lines (comparing charcoal gasification and diesel fuelling) for varying fuel prices calculated at a discount rate of 30%.

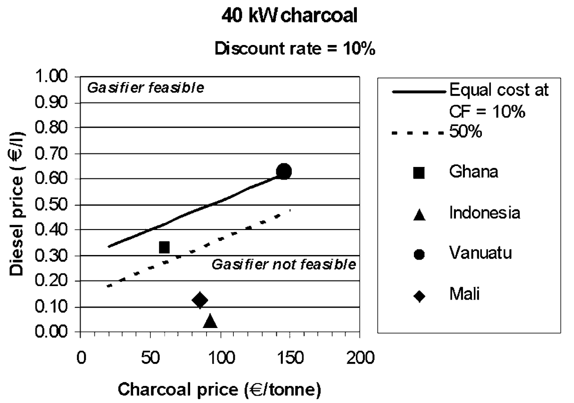

Fig. 7. 40 kW charcoal gasification: Equal cost lines (comparing charcoal gasification and diesel fuelling) for varying fuel prices calculated at a discount rate of 10%.

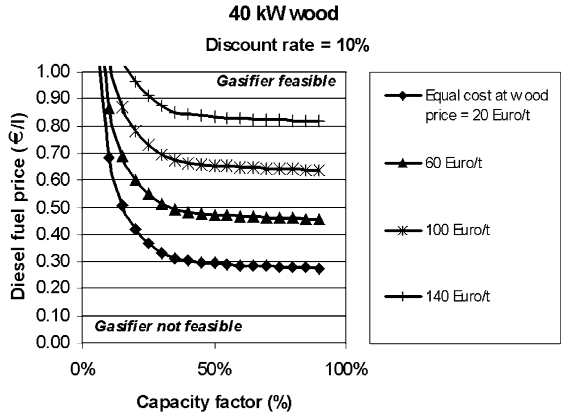

Fig. 9. 40 kW wood: Equal cost lines (comparing wood gasification and diesel fuelling) for varying capacity factors and diesel fuel prices calculated at a discount rate of 10%.

5.1.1. 10 kW charcoal gasification

The graphs (Figs. 4 and 5) show that in Vanuatu charcoal gasification at a capacity of 10 kW can be economically feasible if a capacity factor of at least 50% is achieved. Yet, even at such a high capacity factors a rate of return of 30% cannot be accomplished. It is further clear that charcoal gasification would not be economically feasible in Ghana, Indonesia and Mali, even under very large capacity factors.

5.1.2. 40 kW charcoal and wood gasification

Comparison of Figs. 6 and 9 reveals that the gasification of wood is somewhat more sensitive to the capacity factor than the gasification of charcoal. This is due to the relatively larger involvement of capital in wood gasification. Just as with the 10 kW system, fuel price conditions prevailing in Ghana, Indonesia and Mali prevent the economic feasibility of a gasification project of 40 kW. The situation in Vanuatu is different. There, charcoal gasification projects are generally feasible if capacity factors higher than 10% can be achieved. However, the applicable discount rate should not exceed the level of 10% much. Wood gasification at a capacity of 40 kW is less attractive than charcoal gasification. The best case for wood gasification is provided by Vanuatu, but capacity factors

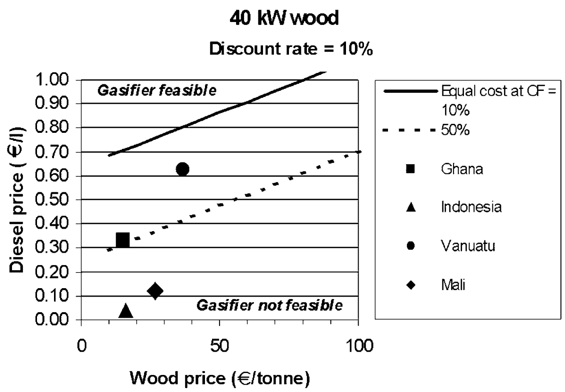

Fig. 10. 40 kW wood gasification: Equal cost lines (comparing wood gasification and diesel fuelling) for varying fuel prices calculated at a discount rate of 10%.

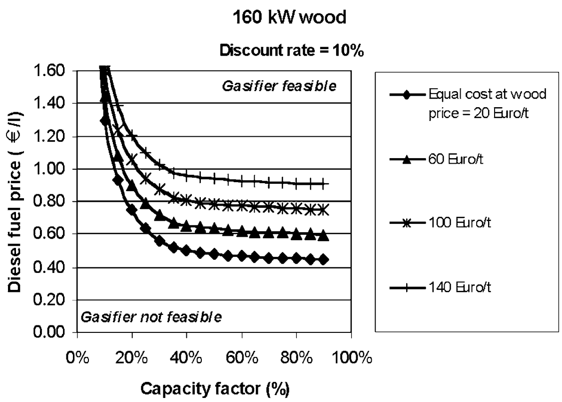

Fig. 12. 160 kW wood: Equal cost lines (comparing wood gasification and diesel fuelling) for varying capacity factors and diesel fuel prices calculated at a discount rate of 10%.

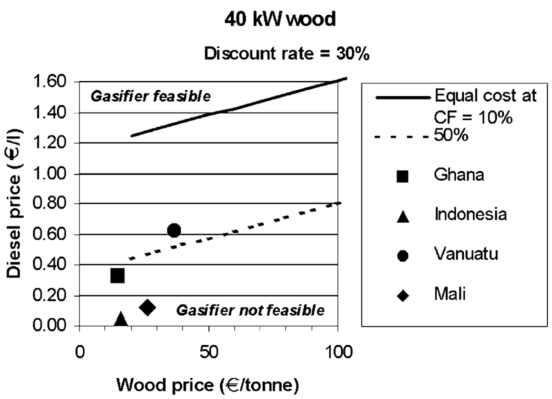

Fig. 11. 40 kW wood gasification: Equal cost lines (comparing wood gasification and diesel fuelling) for varying fuel prices calculated at a discount rate of 30%.

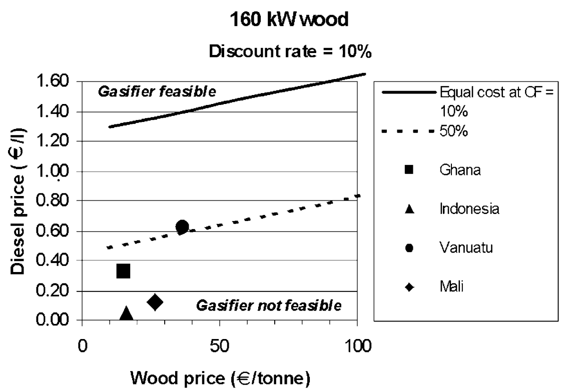

Fig. 13. 160 kW wood gasification: Equal cost lines (comparing wood gasification and diesel fuelling) for varying fuel prices calculated at a discount rate of 10%.

should be substantially higher than 10% to make a feasible project.

5.1.3. 160 kW wood gasification

Especially for capacity factors below 50%, the economic feasibility is very sensitive to the number of kilowatt-hours produced in the case of 160 kW wood gasification (Fig. 12). Figs. 13 and 14 show that in Vanuatu a feasible project achieves a capacity factor of 50%. In Ghana, Indonesia and Mali 160 kW wood gasifiers are not economically feasible.

5.1.4. General

Feasibility of biomass gasification is very site specific due to large differences in prevailing fuel prices on the various locations. Attempts to increase the economic viability of biomass gasifiers by employing them in base load (i.e. at capacity factors higher than 50%), whereas diesel gensets would supply the peak, will not be successful: The best achievable economic conditions have already been accomplished as from capacity factors of 50%.

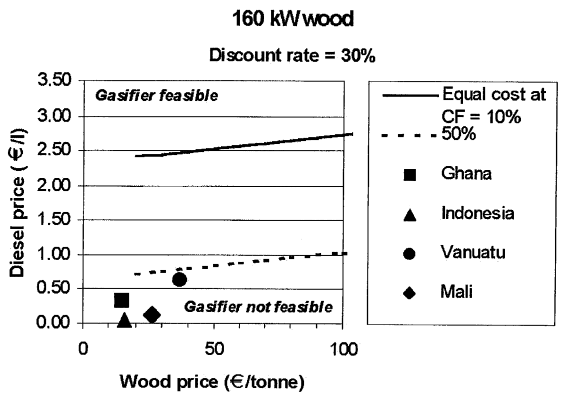

Fig. 14. 160 kW wood gasification: Equal cost lines (comparing wood gasification and diesel fuelling) for varying fuel prices calculated at a discount rate of 30%.

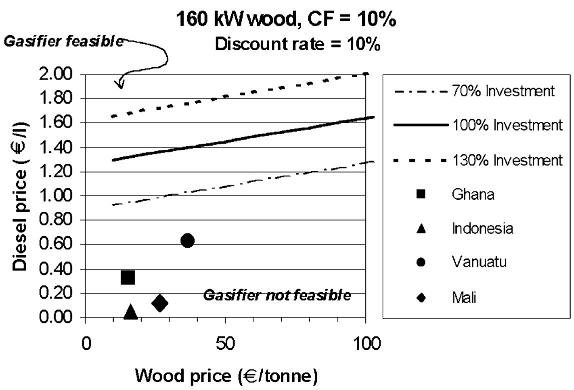

Fig. 15. Equal cost lines for different investment levels at a capacity factor of 10%.

5.2. The investment

The sensitivity to investment level is tested on the 160 kW case (see Figs. 15 and 16). Naturally, the sensitivity to the investment is largest at low capacity factors. Yet, even a decrease by 30% is not enough to make wood gasification a feasible option as long as the capacity factor does not reach a level of about 50%. Near this value, a change in the investment by ±30% can be decisive (compare the case of Vanuatu, Fig. 16).

To find out where cost reductions can be achieved, the investment break-down displayed (Fig. 17) was used. The major cost component in all four gasification cases considered is the gasifier. This item can certainly be produced at reduced cost. Whether the potential of cost reductions is limited to 30% or not is not investigated here. It seems a matter of production volume in the first place.

Substantial cost reductions cannot be achieved by focusing on the engine,[9] but rather on the gasifier. The only way of accomplishing cost reductions is

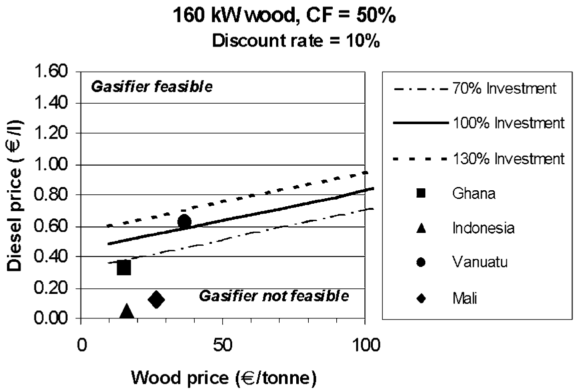

Fig. 16. Equal cost lines for different investment levels at a capacity factor of 50%.

[9] It is sometimes claimed that investment costs may be reduced strongly by employing cheaper gas engines. An alternative to the brand new gas engine, assumed for the 10 kW case, would be to utilize a second-hand overhauled car engine of originally 30 kW, retrofitted from petrol fuel to gas fuel. (Note that the retrofitting of an internal combustion engine from a liquid fuel to a gaseous fuel results in capacity derating. This phenomenon has an impact on capacity-specific investment cost (€/kW).) The engine is expected to show quite a long technical lifetime due to its operation under low-stress conditions (1500 rpm, at a derated capacity of 10 kW only). Full-load equivalent hours of 5000 h may be assumed. Also in the case of the 40 kW gasifier systems (both charcoal and wood gasification) an overhauled and retrofitted car engine (in this case of originally 60 kW) would be technically feasible. The costs of this type of engines may be estimated at 230 and 100 €/kW for the 10 and 40 kW engines, respectively. This is substantially cheaper than the costs of new gas engines (370 and 160 €/kW in this paper). Yet, the influence on the total investment is small (between 4 and 10%, relative to the original investment). If high capacity factors apply, a reinvestment is required during project lifetime. This is due to the relatively short technical lifetime of this type of gas engines. Taking these considerations into account it is concluded that retrofitted car engines are an attractive option for projects with low capacity factors. The employment of such engines is not, though, a decisive means to decrease capital costs to a level which makes gasifier projects economically feasible.

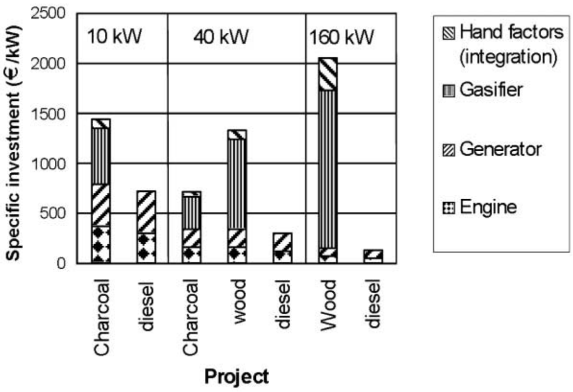

Fig. 17. Investment breakdown for the various gasifier projects and their alternatives.

Table 8
Allowable investment (€/kW) at two discount rates (30 and 10%) and a capacity factor of 10%

Capacity and fuel	Vanuatu			Base case of which Genset
	30%	10%		
10 kW, charcoal	870	960	1400	790
40 kW, charcoal	450	730	710	340
40 kW, wood	700	1030	1300	340
160 kW, wood	630	930	2100	150

by introducing large-scale production of gasifiers. After all, the cost estimates employed until here in this paper are basically about one-off custom built systems. Large-scale gasifier production implies that a large market is required, which in turn means that the scope of application should be wide. They should therefore definitely be aimed for application under the usual low capacity factors of about 10%. At the same time, gasifiers should be attractive for local private entrepreneurs in developing countries. Therefore, discount rates of 30% should be assumed for a determination of allowable investment levels. Values for the typical fuel price levels applicable in Vanuatu are given in Table 8. Drastic cost reductions are required. If instead of private entrepreneurs, utilities are the investors in rural electrification, then a discount rate of 10% was assumed. As a result of the lower discount rate, allowable investments are slightly higher (Table 8). It is clear that charcoal gasification is closer towards market introduction than wood gasification.

5.3. *Fuel prices: the cost of sustainability*

Diesel fuel prices vary from place to place (Table 7). Vanuatu is one of the locations where diesel fuel is most expensive. It is often argued that due to growing oil scarcity diesel fuel prices will rise during the coming decades. That development will definitely create more favourable conditions for biomass gasification at locations to which national electricity distribution grids will not be extended. One reason why diesel fuel may be valued at a higher price is the emission of carbon dioxide associated with the combustion of fossil fuels. Each tonne of combusted diesel oil results in an emission of 3.17 t of carbon dioxide (after Gaur and Reed [13]).[10] Carbon emission mitigation programmes and projects value the avoided carbon dioxide emission at prices in the range of 2–20 €/t CO_2 [14]. In the case of avoided diesel fuel combustion this would be equivalent to 0.005 – 0.05 €/l diesel fuel. The role of biomass energy projects in Joint Implementation projects and the Clean Development Mechanism shows that under circumstances the value of avoided CO_2 emissions can be passed on to biomass energy projects. (A necessary condition is that the biomass utilized is grown sustainably.)[11] The result of applying a value to avoided CO_2 emissions (under the assumption that this value can be made payable in some way) is that the lines drawn in the graphs (Figs. 3–14) shift linearly towards lower diesel fuel prices by a value of 0.005 – 0.05 €/l. In comparison to prevailing diesel prices in most places this shift is obviously negligeable. The conclusion can only be that current prices for avoided CO_2 emissions have no impact on the general observations made in this paper about the role of biomass gasification in rural electrification.

Whether or not the global climate is at stake, sustainability of biomass supplies is a necessity for successful biomass gasification projects. This involves sufficiently high prices to set up and maintain sustainable production systems. With the exception of the biomass prices quoted for Vanuatu, it is not known to

[10] Each tonne of diesel fuel contains 0.865 t of carbon [13]. Upon combustion, each tonne of carbon yields 44/12 t of CO_2.

[11] In the case of charcoal gasification this would set particular terms to the technology by means of which the charcoal is being produced. Zero emission charcoal production is certainly possible.

which extent the prices for biomass fuels referred to in this paper do meet this criterion.

6. Conclusions

To analyse the prospects of biomass gasification for the electrification of rural areas in developing countries, an annuity model to calculate production cost was developed. In order to create an equal basis of comparison, proper account has been taken of the differences in technical lifetime of certain components of the technical systems evaluated. The evaluation method distinguishes two types of parameters: technology and site parameters. The analysis tool thus provided yields discriminating conclusions about the feasibility of biomass gasification under different circumstances. The second basis for the analysis is a set of applicable technology parameters. Part of these is a coherent costing model provided here. The evaluation methodology is also proposed as an assessment tool for quick scans of project feasibility.

Both the economic evaluation tool and the costing model are simplified to such an extent that long-term global conclusions can be drawn. Project development cost, cost for transport of equipment as well as taxes and some other refinements are not incorporated in the evaluations.

It is shown that the value of avoided CO_2 emissions has a negligeable impact on the feasibility of biomass gasification projects.

The capacity range considered (10–200 kW) is covered by an investigation into three cases (10, 40 and 160 kW). For the 10 kW case, the fuel considered is charcoal. Both wood and charcoal are investigated for the capacity of 40 kW, whereas for the largest case (160 kW) wood fuel is investigated. The analysis shows the following:

- Prevailing fuel prices and investment levels suggest that for small-scale charcoal gasification (10–40 kW) conditions for economically feasible projects are easier to satisfy than for slightly larger-scale wood gasification projects (40–160 kW). Especially for the larger capacities of around 160 kW, one explanation is that on a capacity basis investments (€/kW) are substantially larger. This is due to the need for fuel preparation, storage and feeding devices.
- It cannot be excluded that there do exist sites where biomass gasifier systems can be installed and operated in an economically viable manner, even at today's cost levels for these systems. However those sites represent a small niche. They are difficult to locate.
- Although charcoal is more expensive than wood (on an energy basis) it can out compete wood as a fuel for gasification systems at a capacity up towards 40 kW. One reason is the lower specific investment (€/kW) required for charcoal gasifiers.
- A large market for biomass gasifiers can be addressed if a drastic cost reduction is achieved by the manufacturing industry. Allowable cost levels are indicated (Table 8). Most probably the larger 160 kW systems will remain too expensive.

Discount rates are low (10–15%) if the public sector becomes involved. This sector may regard the 10–40 kW charcoal gasification option as potentially attractive if further conditions in the relevant country are favourable (these conditions are mainly determined by fuel prices).

Mass production of biomass gasifiers, resulting in considerable cost reductions, would create chances for the technology. Further consideration of such production can be justified on the basis of a fuel price inventory covering a large number of countries. Readers are invited to plot the fuel price conditions known to them in the graphs presented in this paper and to inform the author.

Appendix A. Definitions

Capacity (*power capacity*): The maximum amount of energy per unit of time which a plant is capable of producing (W).

Capacity factor: (Here used as *annual* capacity factor) The quantity of energy produced by a power plant during one calendar period (here a year) of its economic lifetime divided by the theoretical maximum quantity of energy produced by the power plant during that period (expressed as fraction or as percentage):

$$\text{annual capacity factor} = \frac{\text{energy produced during one year}}{\text{Capacity} \times \text{year}} \quad (\text{Wh/Wh}).$$

Load factor: The quantity of energy produced by a power plant during the period that it is operational divided by the theoretical maximum quantity of energy produced by the power plant during that operational period (expressed as fraction or as percentage):

$$\text{load factor} = \frac{\text{Energy produced during operational period}}{\text{Capacity} \times \text{operational period}} \quad (\text{Wh/Wh}).$$

Note that the calendar period during which the power plant is not operational is not counted as part of the operational period.

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