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Viability of off-grid electricity supply using rice husk: A case study from South Asia

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ABSTRACT

Rice husk-based electricity generation and supply has been popularized in South Asia by the Husk Power Systems (HPS) and the Decentralised Energy Systems India (DESI), two enterprises that have successfully provided electricity access using this resource. The purpose of this paper is to analyze the conditions under which a small-scale rural power supply business becomes viable and to explore whether larger plants can be used to electrify a cluster of villages. Based on the financial analysis of alternative supply options considering residential and productive demands for electricity under different scenarios, the paper shows that serving low electricity consuming customers alone leads to part capacity utilization of the electricity generation plant and results in a high cost of supply. Higher electricity use improves the financial viability but such consumption behaviour benefits high consuming customers greatly. The integration of rice mill demand, particularly during the off-peak period, with a predominant residential peak demand system improves the viability and brings the levelised cost of supply down. Finally, larger plants bring down the cost significantly to offer a competitive supply. But the higher investment need and the risks related to monopoly supply of husk from the rice mill, organizational challenges of managing a larger distribution area and the risk of plant failure can adversely affect the investor interest. Moreover, the regulatory uncertainties and the potential for grid extension can hinder business activities in this area.

1. Introduction

Out of 737 million tonnes of paddy produced in the world in 2012, 90% came from Asia and South Asia contributed about 30% of this production [1]. Rice is cultivated on 60 million hectares in the region and offers livelihood for more than 50 million households [2]. Rice cultivation and processing (i.e. milling) thus form major economic activities in the rural areas of the region. As a by-product of rice production, the region also produces a significant amount of straw (about 225 Mt y^{-1}, assuming a straw to paddy ratio of 1.0), and rice husk (about 45 Mt y^{-1}, assuming a paddy to husk ratio of 0.2) but the residue or waste does not produce any commercial value in most places. A part of the waste is used as fodder (or in animal food preparation) and in brick kilns, while a

Abbreviations: BM, build and maintain; BOM, build, own and maintain; BOOM, build, own, operate and maintain; CDM, clean development mechanism; CNG, compressed natural gas; DESI Power, Decentralised Energy Systems India Private Limited; HH, households; HPS, husk power systems; PoA, Programme of Activities; PV, photovoltaic.

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significant part of it is used as a source of energy, mainly for cooking purposes and for parboiling of rice. The rest is burnt in the field, creating environmental pollution.

However, few attempts have been made in South Asia, particularly in India, to utilize rice husk for electricity generation. The Ministry of New and Renewable Energy in India has been promoting biomass gasification projects under various schemes and it is reported that there are 60 mini rice husk powered electricity plants operating in various parts of the country. But the success of Husk Power Systems (HPS) as a private, off-grid electricity producer and supplier has renewed the commercial interest in this waste-to-electricity conversion. Other countries in the region however have been slow in exploiting the resource commercially. There is a single 250 kW rice-husk based power plant operating in Bangladesh (namely Dreams Power Limited in Gazipur), while Pakistan does not seem to have yet experimented with rice husk as a source of power. The lessons from successful commercial ventures in the region can support wider application of this waste to electricity technology.

Yet, the issue of rice husk-based power in South Asia has not been widely analyzed so far. There are few case studies discussing specific projects or initiatives but there is a dearth of systematic academic studies. The purpose of this paper is to analyze the business model and techno-economic feasibility of rice husk based electricity generation to understand the basic conditions required for developing a viable husk power business. This study thus intends to bridge the knowledge gap indicated above.

The paper is organized as follows: Section 2 presents a review of the HPS business model and DESI Power model; Section 3 considers rice-husk based electricity generation for rural applications with and without rice mill demand and checks for the viability of such a system. It then expands the system size to consider the viability of operation at the village cluster level. Finally some concluding remarks are presented in the last section.

2. Experience of using rice husk for power generation

Rice husk is being used for electricity generation in India in various sizes of plants. Rice husk gasification is commonly used in small-scale plants for electricity access and two commercial ventures, namely the HPS and DESI Power have been quite successful in this respect. This section presents these experiences.

2.1. *The HPS model*

The Husk Power Systems offers an example of an innovative rural electrification business that has combined electrification with rural development by providing access to electricity while ensuring environment protection, wellbeing of local population and empowerment of local communities. The "rural empowerment enterprise", headquartered in Patna, Bihar, was set up in 2007 by a group of like-minded friends who wanted to challenge the conventional perception of rural electrification as a non-viable business proposition. They realized that the low cost electricity supply and high quality service are key factors for a viable, small-scale electricity generation option. HPS looked into various alternative electricity generation options (such as wind turbines, solar photovoltaic (PV), biodiesel, and bio-gas) but selected rice husk, an abundant local resource in the rice-growing region of the country which was hitherto treated as a waste, that can be procured at very low cost for conversion to electricity.

HPS decided to use the gasification technology which is a partial oxidation process in which a solid fuel is mixed with oxygen (air) in a controlled system to produce producer gas. However, husk does not burn easily due to its high silica content and silica-cellulose structure that causes wear and tear of components coming in contact with it [3]. Although biomass gasifiers have been used previously in India, most common applications involved dual fuels where diesel is used as a support fuel but this increases the cost of electricity generation. For a mono-fuel application, a customized, proprietary design of gasification technology was required that can be built and maintained locally without high level technical expertise. The mono-fuel gasifier was locally fabricated and a cheap compressed natural gas (CNG) engine was procured to start the initiative in 2007. The decision of local fabrication of the equipment as opposed to buying from a manufacturer has turned out to be a smart move as this has reduced the capital cost of the plant.

In addition, the company has been relying on smart technologies to reduce operating costs and potential revenue losses. The distribution mini grid uses smart features for remote monitoring of the system. The company uses smart meters for billing purposes and the bill collectors use hand-held data recorders to keep record of the collection made from door-to-door bill collection rounds. The use of insulated cables hoisted on bamboo poles reduces the potential for electricity theft while reducing the capital investment required for the distribution network.

To ensure regular supply of feedstock, the power plants are located in the paddy growing area and more importantly, close to rice mills to create a win–win situation for both. The mill provides a steady supply of husk and offers a base load demand for the power plant that helps achieve a better plant utilization rate for the power plant, which in turn reduces the average cost of supply. The power plant supplies electricity that is reliable and cheaper than the alternative sources like diesel generators. In some cases, the company has integrated the rice mill business to ensure business viability [4] and to internalize the symbiotic relationship with the power plant.

In addition to careful plant siting, HPS has also taken advantage of other income generating opportunities and created a community support system to ensure better integration with the community. It has registered a Programme of Activities (PoA) under the Clean Development Mechanism for its electrification activity that aims at providing electricity to non-electrified areas through renewable energy sources. The PoA will remain active for 28 years (until 2040) and the emission reduction has been sold in advance to generate carbon revenue. Further, the char obtained from burning the husk is used for incense stick making, thereby monetizing the waste. Local women are employed in incense stick-making, thereby reinforcing the development link with the community. It is reported in [7] that a 32 kW plant produces 6 t of incense sticks per year. Silica precipitation is sold for mixing with cement. The innovative approach towards revenue generation from various products surely helps in improving its financial position.

The HPS claims that in the process it returns more to the local community than that it collects through its electricity bills. Each plant engages 3–4 staff – a plant operator, an electrician, a husk loader and a bill collector, who are taken from local youths and trained by the company, through which about 400 $ per month is recycled into the local economy. The rice mills supplying husk to the power plant receive about 25 $ per tonne of husk (or about 2500 $ per year for a 32 kW plant), an extra source of income for the mills that is often shared the rice mill customers through a reduced fee for milling. The incense stick making activity mentioned previously also provides earning opportunities to local women. In addition, in some cases, the bill collector also acts a "travelling salesman" who takes orders from the households, procures them in bulk from the nearby town and delivers to the households for a small commission. This ensures an extra income for the bill collector and the households get their goods at wholesale rates. This inclusive business model (see Fig. 1) has worked well for the company.

The company has successfully extended its business to more than 300 villages to provide electricity to more than 200,000 people installing 84 plants. HPS initiates the process for installing a new plant upon receipt of a request from a village or the local authority, for which an initial deposit is taken from the interested villagers to cover up to three months cost of electricity. Upon enlisting the interest of sufficient number of consumers, the feasibility of a biomass-based plant is carried out, which identifies a secure source of fuel supply for the plant, and verifies the economic viability of the business. The installation process takes about three months and a local team is set up to operate the system on a daily basis. A typical plant can serve, depending on the size of the village and willing consumers, up to 4 villages with about 400 consumers within a radius of 1.5 km of the plant.

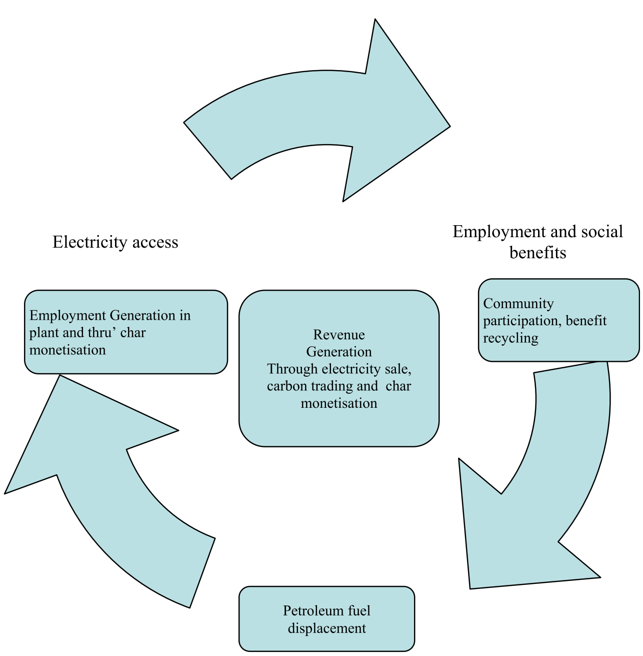

Fig. 1 – The HPS business model.

The supply is given for a fixed period of time, normally for 6–7 h in the evening using a 3 phase 220 V system. Consumers pay a connection charge and a flat monthly fee (varying between 2 $ and 2.5 $) for the basic level of service (2 compact fluorescent lamps and a mobile charging point, called the 30 W package). However, customized packages are also available and consumers with a higher level of consumption benefit from a lower unit rate. Small commercial enterprises are also supplied with electricity but they generally pay a higher flat rate of 4–4.5 $ per month due to higher demand.

The HPS aims to provide electricity to 10 million people in 10,000 villages by installing 3000 plants by 2017. It has successfully managed to secure funds from a variety of sources in the past, including charitable sources and financial institutions. Although the plants initially followed the Build, Own, Operate and Maintain (BOOM) model, the HPS is also employing other modes of operation, namely the Build, Own and Maintain (BOM) and Build and Maintain (BM) lately to grow faster. In the BOOM model, the company looks after the entire chain of the business, which in turn requires a dedicated set of staff that needs growing with new plants. The overhead can be high and the company faces the investment challenge. In the BOM model, the business is partly shared with an entrepreneur who makes a small contribution to capital (about 10%). The HPS maintains the plant and gets a rental fee but the operational aspects are taken care of by the entrepreneur. This reduces some of the management tasks for the HPS, and builds a local network of entrepreneurs but the HPS still faces investment challenge. Moreover, verifying the quality of the local entrepreneur is a challenging task and the speed of replication using this approach remains unclear. The company transfers the ownership after a specified period of time, upon recovering the cost of investment. The Build and Maintain model essentially transforms the HPS into a technology supplier where its role is limited to supply of the equipment for a fee and maintaining the plant through a maintenance contract. The supply business is undertaken by a local entrepreneur and the HPS does not get involved in this activity, although the entrepreneur uses the HPS brand for the supply. Thus the business uses the franchisee model in this case and as long as the franchisee is able to finance the investment and is capable of running it effectively, the business can grow. Although this is a proven approach in many other businesses, in the context of rural electricity supply this has not been widely used. This model requires a strong quality control and standardization of the business operation but it is not clear whether or to what extent this has been developed in HPS.

Thus, a rapid replication of activities which is necessary for achieving the company target of electrifying 10 million people by 2017 depends to a large extent how the above business models work. This expansion demands significant energy resources, financial resources, management capabilities, skilled local staff, and commensurate manufacturing capabilities. It is not clear whether the company can ensure all the success factors to ensure a rapid growth. It is reported that the husk price has significantly increased since its plants have started operation. Moreover, the niche areas for its operation where consumers can afford high tariffs may be difficult to find in the future, which can limit the growth prospect. Critics point out that HPS only operates in niche areas where villages had been receiving diesel-based electricity from local entrepreneurs and the relatively rich consumers in those areas were already paying high charges for their electricity. HPS has thus displaced diesel-based generation by offering electricity at a cheaper rate. In addition, the plant size ranges between 5 kW and 250 kW, which fails to exploit the economies of scale and scope and affects the business prospects. Clearly, the replication issue requires further investigation.

2.2. DESI Power

The Decentralised Energy Systems India Private Limited (DESI Power), a not-for-profit company set up in 1996 with aims to provide affordable and clean decentralized energy to rural communities for rural development, offers an integrated solution comprising of building and operating decentralized power plants, creating rural service infrastructure through mini/micro grids, engaging with the local community for establishing partnership models and organization structures for community-based management of the services, and providing training for capacity building in rural areas for micro-enterprise and business development. These activities are undertaken through sister organizations, such as DESI Power Gramudyog (DPG) for village level businesses and enterprises and DESI Mantra for training and capacity building. In addition, joint ventures and partnerships are also established for energy service and village enterprises.

The first plant of DESI Power was set up in 1996 in a village in Madhya Pradesh (India) and relied on biomass gasification systems. It has set up 16 power plants in total by 2012, with installed capacities ranging between 11 kW and 120 kW. In most cases, DESI Power acts as the rural independent power producer and enters into a power purchase agreement with the buyers' organization (which could be an individual entity, a co-operative society or an association of buyers). It serves mainly rural enterprises and small industries that would otherwise rely on diesel generators for their electricity supply to complement unreliable grid supply. It also assists in the development of micro-enterprises, often linked to agriculture. The company also enters into biomass purchase agreements with local suppliers (who can be villager groups or commercial suppliers).

However, beyond this niche area of operation, DESI Power has also installed four mini-grid systems to supply electricity to households, micro-enterprises and mobile phone towers, where an anchor load (such as the mobile phone towers) is generally included in the system that offers the base load and increases the financial security for the operation. Until 2012, 10 mobile phone towers have been connected to its existing power plants and it plans to expand this to another 20 towers in two years. Moreover, the emphasis is on generating as much electricity as possible through the inclusion of micro-enterprises. This reduces the average cost of supply that in turn enhances viability of the micro-enterprises. This interdependence is exploited to ensure affordable power as well as rural economic development.

In addition to focussing on the niche market, there are other distinctive features of DESI Power approach to the business. DESI Power has installed underground cables to connect consumers, which is a costlier option, although it is less prone to theft and is a more secure option. Its pricing policy is based on the services it offers and not often focuses on electricity pricing as such. For example, for a light point of 60 W a fixed rate of 8.3 US cents (or 5 Indian rupees) per day is charged while micro-enterprises pay a fixed fee for the service. Similarly, one hour of irrigation water supply from a 3.75 kW pump is charged at 1 $ (or 60 Indian rupees) [5]. The company also offers a range of bill collection options – daily for small households and micro-enterprises and monthly for bigger industrial/institutional consumers. Although this appears to be working for them at the moment, the daily collection of revenue is a labour intensive, costly option. Moreover, it follows the Build-Operate-Transfer model of operation wherein it hands over the plant to the local community or village groups after a period of operation.

Like HPS, DESI Power has also registered a small-scale project with the CDM Board for establishing 100 biomass gasifier-based decentralized, power plants in the District of Araria in Bihar state (India). The plants will be of 50 kW capacity with the exception of a few 100 kW plants. In total, 5.15 MW of capacity was expected to be installed by 2012 which will reduce about 360 k tonnes of CO_2 emission over the first ten years of the project. However, with only a few plants set up so far, the company has significantly underachieved in terms of emissions reduction and capacity addition targets. Although the company expansion plan maintains that it aims to achieve its 100 village target in 3 to 5 years, and would establish 5 pilot plants in 2013, the outlook remains uncertain.

Apparently, the investment challenge is the most important barrier faced by DESI Power. While a 50 kW gasifier plant costs 45,000 $, an equivalent diesel generator capacity costs just 10,000 $. In addition, the village co-operatives or associations have limited borrowing capacity and do not have the required deposit or bank guarantees for availing any debt finance. Similarly, in the absence of a bankable agreement with the co-operatives or the buyers, the company cannot finance its projects. This constraint appears to be having a significant effect on the business expansion of the company. In addition, the technical capacity to deliver plants and human capacity to operate and maintain them are also constrained.

3. Business case of power generation from husk

To analyze the economic and financial viability of rice-husk based power supply business, we present a set of cases based on available information and realistic assumptions. The proprietary nature of financial information of existing companies leaves some information gap. Further, some costs, particularly the capital cost of biomass gasifiers can vary depending on the technology source, components used and the degree of environmental protection considered at the project site. The analysis presented here follows a scenario approach where different plant sizes, different levels of

Table 1 – Alternative demand scenarios.

Description	Scenario 1	Scenario 2	Scenario 3
Total number of households serviced	400	400	400
% of HH using basic 30 W service	100%	90%	85%
% of HH using a medium level of 75 W	0%	10%	10%
% of HH using high demand of 250 W	0%	0%	5%
Number of commercial units	20	30	30
Demand by commercial units	60 W	60 W	60 W
Hours of service	6	6	6
Days of operation	365	365	365
Electricity demand (kWh per year)	28,908	34,164	43,800
Required Plant utilization (for a 20 kW plant)	16.5%	19.5%	25%
Plant loading (for 6 h of operation)	66%	78%	100%

Note: HH – households.

electricity demand and alternative capital structures are considered to develop a better appreciation of the range of business outcomes. First, a 20 kW plant is considered, which is followed by a case of 200 kW plant.

3.1. *Providing electricity access to households with a 20 kW plant*

In this case, the plant serves about 400 households, most of whom may be consuming a minimum amount of electricity for lighting and mobile phone charging. However, to allow for different consumption behaviour, particularly by those who can afford to consume more, alternative demand scenarios are developed in Table 1.

In scenario 1, all 400 households use the basic level of electricity and there are 20 small commercial units, each with a load of 60 W. A 20 kW plant can easily meet the demand just using only 16.5% of the capacity (or 66% of the capacity considering a 6 h cycle). The second scenario allows for differential household demand based on consumer mix. It is assumed that 90% of the households use the basic level of demand while the rest 10% use a moderate level of electricity at 75 W per household. In addition, 30 commercial units are considered instead of 20 units each using 60 W. The demand increases marginally but a 20 kW plant still can service the load at 78% loading for a 6 h cycle. The third scenario modifies the residential load slightly to ensure a 100% loading of the plant. Yet, as the plant runs for a fixed period of 6 hours, its overall capacity utilization does not exceed 25%. This is relatively low for a power generating plant.

The financial analysis of the 20 kW generator plant is based on the following assumptions:

a) The capital cost per kW of installed capacity is taken as 1300 $. The Indian companies like HPS or DESI Power have reported a much lower cost (800 $ kW^{-1}) but HPS manufactures its gasifiers locally using its own design while DESI Power procures its technology from Netpro, promoted by DASAG, which is also a stakeholder of DESI Power. Such special cost advantages may not be available to other projects, which justify a higher cost used here. It is important to mention that a recent report [10] has suggested much higher costs based on a project in Cambodia.
b) The cost of distribution network per kilometre is taken as 2000 $ km^{-1}. This cost can vary depending on the quality of the network, materials used, terrain, and cost of labour. For underground cables, the cost may be higher while for distribution systems using bamboo poles, it may be lower.
c) The monthly operating cost is considered to be about 100 $ [6,7] – or about 4% of the capital cost.
d) Each plant employs four employees with a salary of 100 $ per month on average, which is close to the monthly salary cost of 380 $ indicated in [7].
e) The plant life is taken as 15 years and the plant operates 6 h per day, every day of the year.
f) Husk price is taken as 25 $ per tonne and it is assumed that the fuel price remains unchanged over the project lifetime.

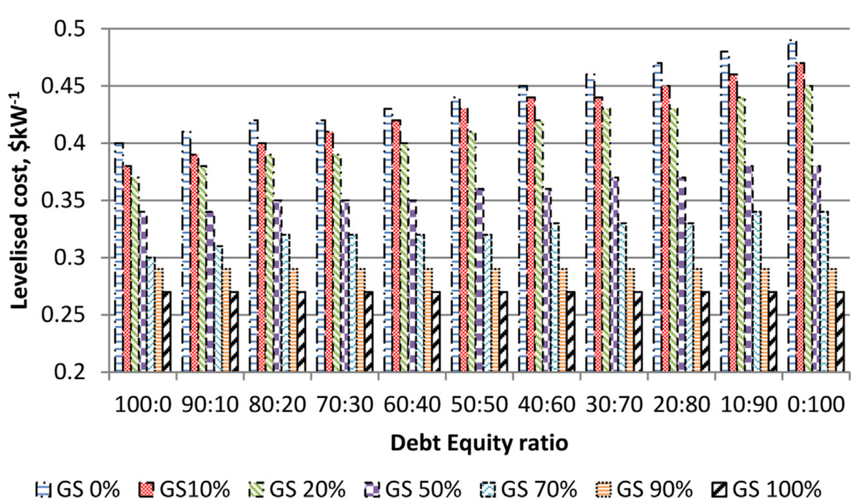

Fig. 2 – Levelised cost of electricity supply for scenario 1. Note: GS – grant share.

g) The lower calorific value of husk on dry basis is taken as 12.6 MJ/kg [3, 4] and the conversion efficiency of gasifier is taken as 20%.
h) The cost of debt is taken at 5.5% y^{-1}while the rate of return on equity is taken as 10% y^{-1}. The weighted average cost of capital is used to determine the discount rate.
i) A straight-line depreciation is used after allowing a 10% salvage value for the asset at the end of its life. Where grant capital is used, it is assumed that the grant capital reduces the capital required for investment and the depreciation charge is reduced accordingly. Although the grant capital can be treated differently in accounting terms, the above provides a simple treatment of the grant.
j) It is assumed that the company is not paying any tax and hence the tax benefit arising from debt capital does not apply here.

The cost of electricity supply for different scenarios and considering alternative debt-equity combinations and grant capital share is calculated. The levelised cost of electricity supply is used as the indicator. The levelised cost is the real, constant cost of supplying electricity that if recovered from consumers over the lifetime of the plant would meet all costs associated with construction, operation and decommissioning of a generating plant. This generally considers capital expenditures, operating and maintenance costs, fuel costs, and any costs involved in dismantling and decommissioning the plant. Equation 1 provides the mathematical relationship for the levelised cost of electricity.

$$\text{LCOE} = \frac{\text{Present value of (capital cost + O\&M cost + fuel cost)}}{\text{Present worth equivalent of (electricity consumed)}} \quad (1)$$

For scenario 1, the result of the levelised cost analysis is shown in Fig. 2. As expected, the lowest levelised cost is obtained when the entire capital requirement comes from grants and the cost for this scenario comes to 270 $ MWh^{-1}. But if no grant is received, the cost of supply that has to be borne by the consumers varies between 400 $ MWh^{-1} to 490 $ MWh^{-1} depending on the share of debt and equity. This clearly shows that part load operation of the system is a costly option despite the low capital cost per kW compared to other technologies (such as solar PV or wind). Clearly, both HPS and DESI Power have realized this and used adequate households and/or micro-enterprises to ensure high plant capacity utilization.

However, the important issue is whether or not a flat rate charge of 2 $ or 2.5 $ per month per household can recover the expenses in scenario 1. As the consumers use only 5.5 kWh per month, their effective tariff varies between 0.36 $ kWh^{-1} and 0.46 $ per kWh depending on 2 $ and 2.5 $ monthly charges, which is considerably higher than the prevailing rate for grid-based electricity. Therefore, as long as the levelised cost of electricity supply is below the above tariff, the business becomes viable in this scenario. If the company charges 2.5 $ per month, even without subsidy it can operate the business profitably as long as the debt–equity ratio is not worse than 50:50. If it charges 2 $ per month, the company needs at least 50% capital grant subsidy to run the business, unless other sources of income can make up for the loss. As other income tends to be limited in nature, it becomes clear that providing access to poor households with limited demand remains a vulnerable business.

In scenario 2, the levelised cost of supply reduces to 0.24 $ per kWh for a capital subsidy of 100% while the cost varies between 0.34 $ and 0.42 $ per kWh for no capital subsidy (see Fig. 3). Although better plant utilization reduces the levelised cost of supply, the revenue would not change if all residential consumers are charged at the same rate. Consequently, when different consumer categories use different levels of electricity, a differential tariff is required to recover the cost. A higher flat rate for the high-end consumers constitutes a simple solution in this case, which may end up in a lower average rate for this category due to higher electricity consumption. The tariff per Watt instead of watt-hours is thus a simple but effective way of passing higher charges to poorer consumers in disguise.

In the third scenario where the capacity is fully utilized for the 6 h period of supply, the levelised cost reduces even further. This scenario, as expected, produces the lowest cost of supply (see Fig. 4) and the levelised cost with full grant funding compares quite well with the low rates reported by HPS. It needs to be mentioned that this analysis used a higher capital investment cost compared to that reported by HPS, which excludes the possibility of achieving the same outcomes as HPS. The result of this scenario supports the claim made by HPS that they are in an advantageous position compared to other renewable technologies. Yet, the levelised cost of supply still remains quite high compared to the grid-based supply in the absence of any capital subsidy. However, the tariff for grid-based supply may not be a true comparator given the unreliable and poor quality of supply. Consumers tend to spend considerably higher amounts for alternative sources of supply (e.g. from generator sets). Accordingly, the willingness to pay for a reliable supply is likely to be higher than the tariff for grid supply, particularly for commercial and industrial consumers.

Once again, a differential tariff will be required to ensure adequate revenue generation. From the company's perspective, running the plant near its full load will ensure higher profitability and clearly, this will ensure that the operation can be sustained with limited or no financial support. But grant capital surely contributes towards risk mitigation and acts as an incentive for the supplier.

It can be concluded that limited electricity supply for a fixed duration can be effectively provided using the rice-husk based system. The cost-effective operation of the system however requires careful control of two factors: 1) that the plant capital cost needs to be minimized, perhaps through

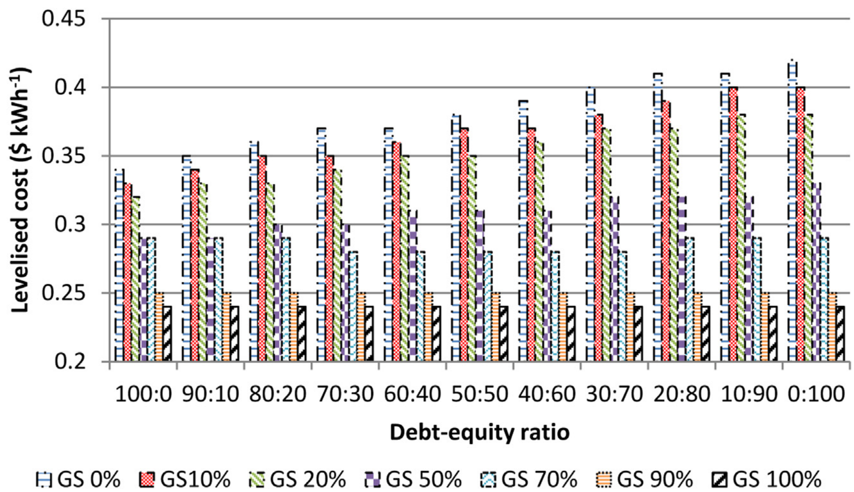

Fig. 3 – Levelised cost of supply for scenario 2. Note: GS – grant share.

local and indigenous design of the plant; and 2) the plant is operated near full load by enlisting adequate number of consumers, preferably with some demanding more than just the basic level of supply (30 W per household). Although the cost of supply remains higher than the prevailing grid-based supply, the business can be run viably with a suitably designed tariff system. The difference in the approach between HPS and DESI Power can be understood from this analysis. HPS has ensured viability by enlisting adequate number of residential customers whereas DESI Power enlisted the support of micro-enterprises. This avoids reliance on a large number of very small consumers as the business or commercial load tends to be much higher than the basic level of residential demand. However, the cost per kWh incident on the poor tends to be higher than those consuming more in the absence of any cross-subsidy or direct subsidy. This tends to be true in any electricity system – more so in a privately owned and operated system, but mitigating measures are often used through direct social safety nets and/or subsidized supply schemes. Hence any support for additional income generation will surely be beneficial.

3.2. *Electricity access with rice mill as an anchor load*

Given that the electricity plant in the previous case has idle capacity outside the evening peak hours, the power plant could consider adding new demand to improve its financial viability. The rice mill offers such a load: it may not have a good quality power supply and the cost of supply may be much higher than the rice-husk based supply. This alternative case is considered below.

Clearly, the energy demand for a rice mill will depend on its size, processing activities involved, level of automation, operation time and such factors. For the purpose of this analysis, the following assumptions are made:

a) The rice mill capacity is chosen in such a way that adequate husk can be sourced from the mill to meet the demand for electricity generation;
b) Small mills in a village or small town location tend to be indigenously made and tend to consume more energy. It is assumed that the electricity consumption requirement per ton of raw rice processed is 43 kWh Mg^{-1} [3].

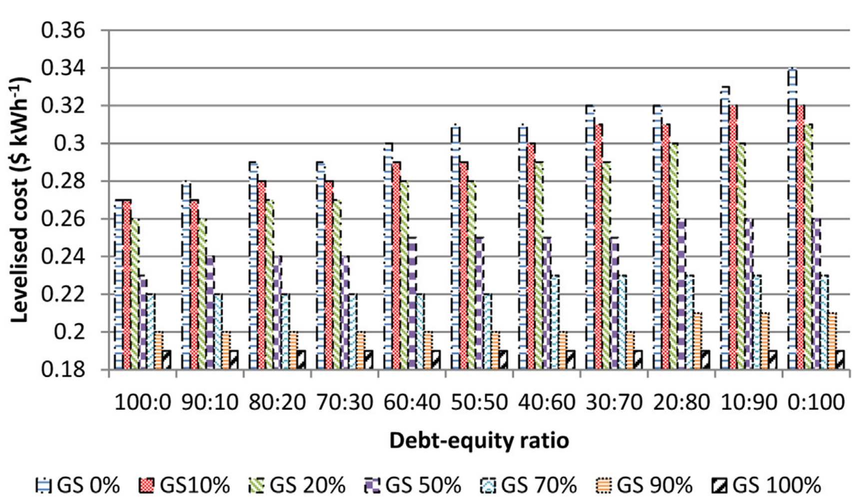

Fig. 4 – Levelised cost of electricity supply for scenario 3. Note: GS – grant share.

c) Rice mills in India can be categorized into two broad groups: small sized ones with less than 1 tonne per hour processing capacity and bigger mills. Small mills generally operate a single shift of 6–7 hours for about 200 days (i.e. 1200 h of annual operation) while larger mills run two shifts (between 2400 and 3000 h of annual operation). In this case, we assume a single shift operation for 1200 h per year.
d) Husk availability is estimated considering a husk to paddy (or raw rice) ratio of 0.2.
e) It is assumed that the rice mill operates during day time when the residential demand is not serviced. This in effect extends the hours of operation of the power plant. Electricity demand is unlikely to be constant for the entire period of operation. It is likely that the evening load may be higher than the day load. For the sake of simplicity of financial analysis, an equivalent plant loading is used that generates the total amount of electricity required to meet the total demand.
f) Scenario 3 from the previous section is used for electricity demand for non-mill purposes.
g) The power plant operates two shifts of 6 h and instead of 4 employees uses 6 employees, each receiving a monthly wage of 100 $. This is logical given that the work for bill collector and the plant technician does not increase proportionately with hours of plant operation.

The rice mill has to be such that it produces enough rice husks in a year to meet the electricity needs of the mill and the village community. Given that the electricity demand corresponding to scenario 3 is 43.8 MWh, and considering 43 kWh electricity required for processing one tonne of rice, we find that a rice mill of 0.4 t h^{-1} capacity operating in a single shift of 6 h for 200 days in a year will produce sufficient rice husk. The rice mill will require 20.64 MWh of electricity and the power plant needs to produce at least 64.44 MWh per year. The rice mill will process 480 tonnes of raw rice per year and will produce 96 tonnes of husks per year. The power plant will require approximately 93 tonnes of husks for its operation, which can be procured from the rice mill directly.

Fig. 5 presents the levelised cost of supply for the integrated power supply operation to the rice mill and the village community. As can be seen, the cost of supply reduces considerably in this case due to higher plant utilization rate. The lower end prices with capital subsidy will be quite attractive to most consumers. Even otherwise, the cost of supply reduces significantly. Hence, it makes economic sense to extend the supply to the rice mills, particularly when the operation does not coincide with the peak demand. This will benefit the rice mill by reducing its dependence on grid electricity, and providing a reliable supply at a reasonable price. Other consumers also benefit from this integration as the overall cost of supply reduces.

Although rice mills can install power generating stations for own use, such installations may not qualify for government support schemes for rural electricity supply. Moreover, the skill requirement is very different for operating a power plant and electricity distribution business compared to running a rice mill. In organizational terms, it makes better sense to have separate entities dealing with two separate businesses but linked to each other through contracts for fuel supply and electricity supply. Such contractual arrangements are important to ensure risk sharing, bankability of investments and reliability of business operations. The captive power supply model used by DESI Power follows this example.

4. Viability of a scaled-up electricity supply system

Rice is the staple food of 1.7 billion people in South Asia. Rice is cultivated on 60 million hectares of land in the region and about 225 million tonnes of rice are produced annually, contributing 32% of global raw rice production. Five major rice producers in the region are India, Bangladesh, Pakistan, Nepal and Sri Lanka. India produced about 158 Mt of raw rice (or paddy) in 2012 [1] and has a total rice milling capacity of about 200 Mt per year [8]. In addition, Bangladesh produced 51 million tonnes of paddy in 2012 while Sri Lanka, Nepal and Pakistan produced about 17 Mt of paddy [1].

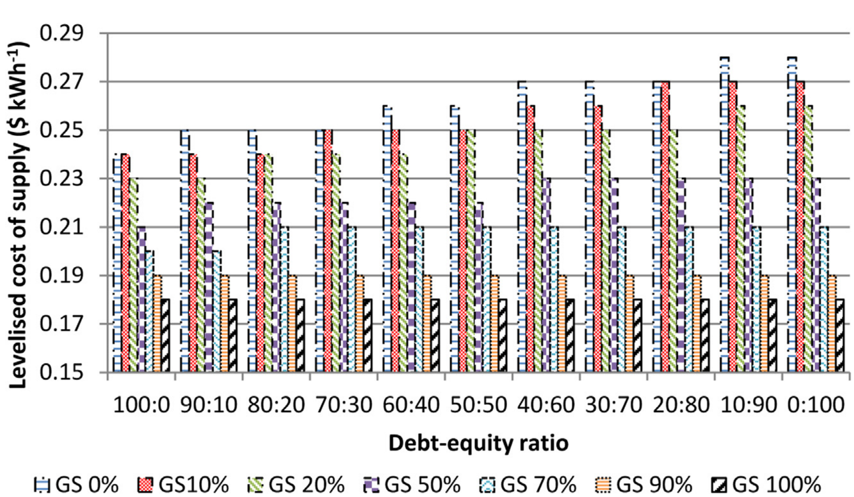

Fig. 5 – Levelised cost of electricity supply for integrated operation. Note: GS – grant share.

Table 2 – Potential for serving large consumer bases.

Mill capacity ($t\ h^{-1}$)	Husk production ($t\ y^{-1}$)	Potential electricity output ($MWh\ y^{-1}$)	Mill consumption ($MWh\ y^{-1}$)	Excess electricity ($MWh\ y^{-1}$)	Number of basic demand consumers that can be served
2	960	672	206.4	465.6	7087
3	1440	1008	309.6	698.4	10,630
4	1920	1344	412.8	931.2	14,174
5	2400	1680	516	1164	17,717
6	2880	2106	619.2	1486.8	22,630
8	3840	2688	825.6	1862.4	28,347
10	4800	3360	1032	2328	35,434

Rice milling takes place both at the household level (using hand pounding or pedal operated systems) and in rice mills. Generally, a small amount of raw rice is processed at the household level, mostly for own consumption. The processing of raw rice takes two forms: dry hulling which tends to account for a small share of total paddy processing and processing of parboiled rice. Rice milling in the region was a licensed activity for a long time that reserved the activity to small and medium-scale industries. This resulted in the proliferation of small mills throughout the region. However, these mills tend to be inefficient and produce poor quality output (higher percentage of broken rice). Moreover, because many of them fall under the unorganized sector, there is no systematic information about the number, distribution and size of rice mills. However, it is generally believed that the mini mills can process 250–300 kg of paddy per hour, small mills have a capacity of 1 tonne per hour whereas larger, modern mills have capacities ranging from 2 tonnes per hour to 10 tonnes per hour. Smaller mills operate a single shift of 6 h while modern mills operate 2 shifts or even 3 shifts but tend to have a seasonal operation.

Assuming a 2-shift operation of modern rice mills for 200 days per year, and considering that about 30% of the electricity that can be produced from the husk can be used to meet the energy needs of the mill, a simple estimation is made of potential excess electricity and the potential number of consumers that can be served to meet the basic demand of 30 W per consumer for 6 h a day for every day of the year (see Table 2). It can be seen that thousands of consumers can be served by such power plants and a large cluster of villages (or blocks) can be considered as the basic unit of electrification. Alternatively, excess electricity from the mills can also be sold to the grid if mills are grid connected or can be sold to a small number of local productive users (e.g. irrigation pumps, flour mills, food storage, etc.). Such larger plants thus open up the possibility of including productive applications of electricity beyond rice mill use, which in turn can catalyze economic activities at the village level. Although agriculture is the main rural activity in South Asia, food processing and other agro-based industrial activities (such as storing and warehousing), play a limited role yet due to lack of infrastructure and reliable electricity supply. While small-scale generating plants can only provide limited supply to households and small commercial consumers, larger plants can act as an agent for rural development.

In terms of cost of supply, two opposing forces are expected to operate. On one hand, the unit cost of generating plant ($\$\ MW^{-1}$) is likely to reduce as the size increases. On the other, the fuel cost, distribution cost and wages would increase. The fuel cost increases proportionately with power generation. The area to be served may increase disproportionately and the extension of low voltage lines over long distances will increase distribution losses and affect power quality. This will require a distribution system at 11 kV or higher voltage level and accordingly, the cost will increase. Finally, the staff requirement will increase in proportion with the area being serviced. Billing and collection cost can

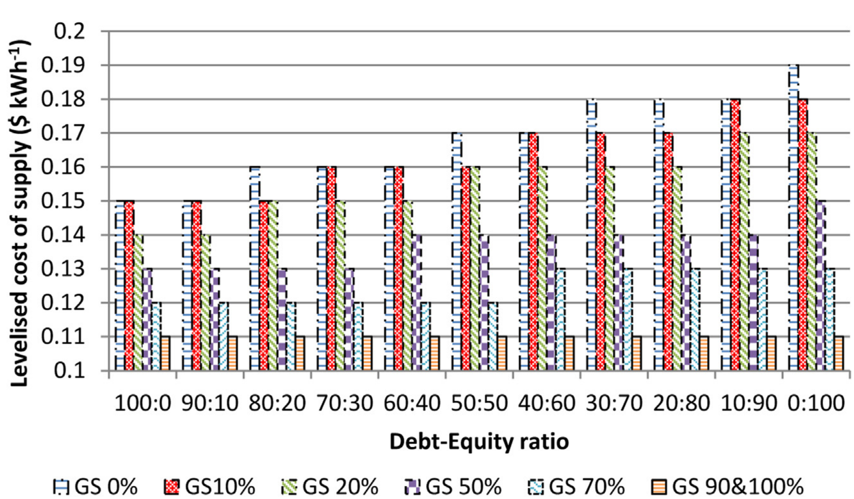

Fig. 6 – Levelised cost of electricity supply for a 200 kW plant. Note: GS – grant share.

increase rapidly. Accordingly, the accurate cost estimation is rather difficult in this case.

To obtain a rough idea about the economic viability of a larger plant, the following assumptions are retained:

a) A rice mill of 2 t h^{-1} is considered. This can feed an electricity plant of 200 kW.
b) the capital requirement per kW to be 1000 $ for a 200 kW plant;
c) 25 staff will be employed for generation, distribution and supply management;
d) The distribution system is extended over a distance of 20 km;
e) Other assumptions remain unchanged. It is possible to consider 24 h operation of the power plant but in this case, the available rice husk can support a smaller power plant capacity. Moreover, a husk-based plant is unlikely to operate continuously for 24 h. In this case, a back-up will be required. For these reasons, a two-shift operation is retained here.

The levelised cost of electricity for no subsidy case comes to 190 $ MWh^{-1}. The cost reduces further with different levels of subsidy (see Fig. 6). The levelised cost in this case is the lowest of all options considered in this study. Clearly, this shows that as long as sufficient number of willing consumers can be enlisted, and the power supply company can manage to run its village cluster level operations, a bigger business can be profitably run. Alternatively, the excess power can be sold to captive users or to the grid at a break-even price of 190 $ MWh^{-1} to make the venture viable. However, the tariff offered by the utility for buy-back is not as remunerative as this, which hinders financial viability of such power plants.

Clearly, such a scaling-up of the business has its pros and cons. A bigger plant and larger area of operation may be more attractive to investors willing to enter in the mini-grid business. Such plants offer some economies of scale and therefore can be a more efficient option economically. It may also be possible to take advantage of carbon credits either through the CDM programme or through other voluntary offset schemes. The byproducts of electricity production and the symbiotic relationship between the rice mill, power plant and the local community can support such systems positively.

Yet, the risks involved in such an integrated operation cannot be overlooked either. The power plant is heavily dependent on the rice mill and any break-down in the mill or its closure will jeopardize the power plant operation. A 200 kW plant would require about 1000 tonnes of husks per year for its operation and procuring such a volume of husk from an alternative source can be difficult. The transportation cost of feedstock can easily increase the fuel supply cost and render the electricity supply less cost effective. Similarly, if the mill does not settle its electricity bills regularly or delays in making the payments, the bad debt can increase and the cost of running the business can increase. Diversifying the commercial demand can mitigate the over-dependence on the rice mill.

Similarly, as the plant serves a larger area, any fault with the generating plant will result in a power supply disruption in the entire area. While installing two 100 kW plants can be a better option, the capital cost may increase. In addition, the plant would need regular maintenance on a daily basis to ensure proper cleaning of the gas filters and this makes it difficult to run the system continuously. It is likely that a back-up system will be required to meet the essential demand for a limited period of time. Depending on the fuel or technology used, the back-up system can increase the overall cost of electricity supply. Similarly, the distribution network would require greater attention and any fault in the distribution system can reduce the system reliability.

The investment requirement for a plant of 200 kW can easily reach 250,000 $. This is a substantial investment in a rural location, and companies willing to enter into such businesses will need to muster adequate financial resources and relevant experience. Securing long-term debt funds from the financial institutions can be a major challenge as many of them require more than 100% guarantee for such loans. In addition, the loan term (period and interest rate) may not be favourable to this type of businesses. Project financing of mini-grids can be challenging due to limited number of bankable contracts with consumers. Any support from the government and international agencies in facilitating finances through credit facilities, grants and guarantees can be helpful.

The investment challenge amplifies due to regulatory uncertainties in the area of off-grid electrification. As indicated in [9], the supply of electricity through a local off-grid network requires conventional regulatory supervision due to the possibility of monopolistic exploitation of the consumers, supply quality concerns and potential disputes between the supplier and the consumers. However, the regulatory arrangement for mini-grids is not quite clear in many South Asian countries. It appears that the rural areas covered by off-grid supply still come under the jurisdiction of the utility providing the central grid-based supply. Any decision to extend the grid subsequent to the installation of the off-grid plant can make the off-grid business unviable and stranded. Thus, the regulatory uncertainty needs urgent consideration.

5. Conclusions

This paper has considered off-grid electrification through electricity generated from rice husk in South Asia. The Husk Power Systems has successfully used rice husks to provide decentralized electricity in rural areas of India and has so far installed 84 plants to electrify 300 villages. The success of the HPS can be traced to their choice of technology that is less capital intensive compared to other renewable energy options, their innovative approaches towards system cost reduction (e.g. using temporary structures made of bamboo poles for distribution network, local manufacturing of gasifiers) and additional income generation (e.g. use of carbon offsets and monetization of byproducts), careful tariff design linked to Watts of demand instead of Watt-hours of energy used and careful siting of plants where about 400 customers are willing to pay for the service. DESI Power on the other hand has placed emphasis on productive use of power and used husk-based systems to displace diesel-based electricity supply to micro-enterprises. It has also used anchor loads (such as supply to mobile telephone towers) to improve the financial viability of the business.

The financial analysis of rice husk-based power generation shows that the levelised cost remains high compared to the supply from the centralized grid when just the basic demand (of 30 W) of households is met. This is due to low plant utilization factor but the tariff based on Watts helps generate the required revenue to run the system. As the system utilization improves either due to higher electricity consumption by some or by integration of the supply system to the rice mill, the levelised cost of supply reduces. However, the benefits of such cost reduction are enjoyed by those who consume more when an inverted block tariff system is used. The integration of rice mill's electricity demand brings the costs down considerably due to extended use of the facility during off-peak hours. Such integration can ensure an anchor load and can be beneficial for the electricity supplier. The rice mill on the other hand benefits from a reliable supply at a comparable price and reduces its cost arising out of electricity disruption. While the rice mill can develop a power plant for its own consumption, it is better to allow a specialized, separate entity to deal with the power generation business and develop contractual arrangements for fuel and power supply.

The extension of the analysis to include larger power plants for electricity distribution to a cluster of villages results in the cheapest cost of supply due to realization of economies of scale. The cost of supply in such a case can be very competitive even without any capital grants. This suggests that it makes economic and financial sense for a supply company to extend the business to cover larger areas as long as there are sufficient willing customers and adequate supply of rice husks from rice mills. This also can promote economic activities in rural areas and promote economic development urgently needed to reduce rural poverty. Yet, the regulatory uncertainty, limited access to financial resources and markets, increased complexity of the distribution network (i.e. it may require higher voltage permanent network systems to reduce losses), and higher dependence on a single or limited fuel supply source would have to be carefully considered. Such bigger systems would require careful system design to ensure adequate system reliability, appropriate maintenance and limited line loss in distribution.

Being a major rice producing region, South Asia surely has a significant potential of utilizing a major agro-waste to produce electricity for rural supply and rural development. However, to realize the potential the barriers mentioned above need to be addressed. In addition, the potential for using rice straw alongside rice husk can also be considered for power generation. Similarly, the potential for replication of this business in South Asia needs further analysis.

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