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A Potential Role for an AMC in Supporting Dish/Stirling Concentrating Solar Power

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CASE STUDY ANNEX
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Executive Summary

This annex sets out the potential justification for, and design considerations of, an Advance Market Commitment (AMC) to improve the long term economic viability of dish/Stirling concentrating solar power for rural electrification. The case study uses Rajasthan, India, as an illustrative example location for such an AMC. It complements Vivid Economics' report providing a broader economic assessment of the economics of AMCs. A further annex considers how AMCs might be used to promote the development of green mini-grids in Tanzania. The two cases are intended to illustrate the AMC concept. They are not project proposals and have not been subjected to the level of scrutiny an actual proposal would be.

Dish/Stirling concentrating solar power (CSP) converts solar heat into electricity by focusing solar radiation onto a receiver containing a heat engine known as a Stirling engine. The technology is modular, with each unit typically generating output of 3-25 kW. There are presently a small number of potential suppliers of such products. Commercial applications of the technology are currently either small-scale or pending. Large-scale power stations are expected to be built in the US, likely to ensure economies of scale in manufacturing; but the economic and logistical feasibility of decentralised deployment in developing countries will not be tested by such applications.

The justification for a technology-specific dish/Stirling AMC would lie in expanding the technological options that can be used in rural electrification. Renewable technologies are often highly dependent on the availability of suitable resources on site. Targeting support specifically on removing the market barriers to a solar thermal technology would potentially provide a further electrification option for those locations without suitable wind or water resources.

The potential market for the technology within an area such as Rajasthan depends on the extent of (and satisfaction with) grid connection, the cost of

substitutes, typical load requirements and the availability of solar and alternative resources. A conservative estimate suggests that the potential market in Rajasthan could be of a few hundred units, but key data gaps make this estimate conjectural and preliminary.

The main market barrier is a lack of confidence over the feasibility of operating and maintaining dish/Stirling units in a decentralised, developing world context. The aim of the AMC would be to remove this barrier. The AMC would provide incentives to attempt decentralised application and hence a phase of learning and cost reduction in operation and maintenance (O&M). If successful this would enhance the technology's reputation and prospects of long-term sustainable demand. Operators would need to demonstrate to themselves, financiers and customers that concerns over reliability could be alleviated and that O&M support could arrive quickly if required. Estimates of the technology's cost of generation are few, but are comparable to other off-grid technologies, indicating that it need not be a market barrier.

To overcome this barrier, the AMC would provide operators with a visible certain price either per kW installed, per kWh generated, or per user connected. Each of these options has its respective pros and cons. Per kW installation payments have been criticised for not providing incentives for ongoing supply, but would be simpler and easier to control the budget for than per kWh payments. In either case, to reduce the risks associated with removing the flexibility of amending prices in response to changing costs (which may be particularly problematic for immature technologies where costs are uncertain), the support mechanism could be designed to evolve over time to take account of new information on costs.

The overall price fixed by the AMC would have one component provided by subsidy and one component paid by users of the technology ie it would involve co-payment. The rationale for co-payment is derived from the properties of the target product and its market. First, the AMC is designed to support a product for which there are plenty of direct substitutes. Co-payment decreases the likelihood that the technology will be deployed in favour of more cost-effective alternatives, given that consumers will opt for the cheapest, most suitable option. Secondly, the product generates an ongoing service rather than offering a one-off benefit. Therefore, it risks being stranded and falling into disuse if it is not deployed where it is genuinely valued, as signalled through co-payment.

The small number of potential suppliers and the risks inherent in deployment suggests that bilateral negotiations may be preferred to a bidding mechanism or administratively-set price. A well-designed competitive bidding mechanism reveals information on the prices at which suppliers are able to provide goods, which an administratively-set uniform price can only estimate. However, given the great uncertainty in potential profitability, suppliers may be extremely conservative in their assessments of the supply contracts they can commit to, leading to a lower overall quantity than desired. Bilateral negotiations may be preferred in order to incorporate such concerns.

1 Overview

1.1 Introduction

The purpose of this case study is to illustrate how the stages of a preliminary assessment for a technology-specific AMC might look. It is designed to complement the more theoretical and generic analysis in the main body of the report by presenting the practical considerations for an AMC for a particular technology. The case study should not be read as a proposal or recommendation to implement an AMC for this particular technology. The case study has not been developed to the level of detail of an actual project proposal would be.

The case study uses Rajasthan as a geographical focus. The AMC assessment process requires an idea of the potential market for the product within a specified geographical range. Rajasthan is used here to provide descriptive context associated with a particular location. India is a country with a known need for further rural electrification, and a national government generally supportive of solar power and incentivising off-grid electricity generation in rural areas. The north-west corner of India has the best solar resource in the country, and is therefore the area where CSP would be most cost-effective. However, the document should not be read as a proposal to implement such a policy in India.

The case study poses four key questions:

— *What is the rationale for an AMC?* The first hurdle which a technology specific AMC proposal should pass is the establishment of a *prima facie* case for it. The possibilities that the technology is fundamentally flawed for the context in which it will operate, destined to remain significantly more expensive than alternatives or to have no advantage over them, or is already well-supported by other policies, are considered.

— *What is the potential market for the product*? It was noted in the main report that there are three main ways the AMC can take effect: through outright government purchase; through placing a mandate on private actors; and through incentivising private actors to purchase the product. The question of potential market is particularly relevant in AMCs following the latter model, which includes that described in this case study. Further, once support is withdrawn, the product should be commercially viable on its own merit, requirement an assessment of the the potential market.

— *What are the current barriers to market development?* Current demand for the product may be low or absent because it is simply more expensive than conventional alternatives. Alternatively, there may be other market barriers, such as capital constraints, lack of appropriate skills or lack of familiarity. The AMC design should target removal of specific market barriers.

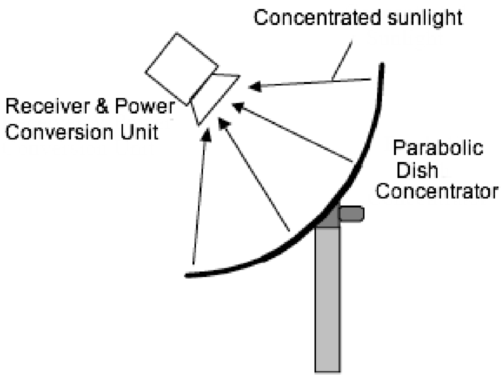
— *What are the different options for AMC design?* The pricing mechanism and the variable to which payment will be linked (installed capacity, number of households, etc.) are two of the most important considerations for AMC design.

1.2 The candidate technology

Concentrating solar power converts solar heat into electricity, using reflective material to focus solar radiation in order to power a mechanical device such as a steam turbine or heat engine. It therefore differs from solar photovoltaic technology which transforms *light* directly into electrical energy through use of semiconductors.

There are several types of CSP technology. This case study deals exclusively with dish/Stirling CSP, in which a parabolic dish focuses solar radiation onto a receiver containing a Stirling engine (Figure 1 below). Other CSP technologies, such as parabolic trough, linear Fresnel and power tower, are unsuited for small-scale or modular applications.

Figure 1 Dish/Stirling systems generate electricity by using concentrated solar radiation to drive a heat engine

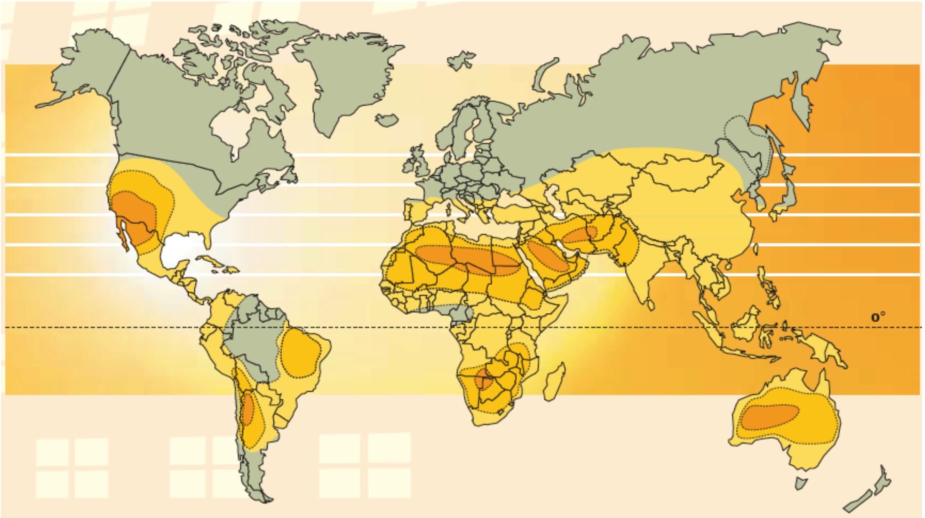


Source: US Department of Energy[i] (see endnotes for additional references for figures)

The economic viability of concentrating solar power is highly sensitive to the solar resource available. The technology requires direct normal irradiance of at least 1900-2000 kWh/m²/year in order to be economically feasible. Areas with sufficient insolation include most of the developing world, as well as the US, Australia and southern Europe. Excessive cloud cover precludes its use in some tropical low latitude climates. Its appropriate geographical range is shown in Figure 2.

Options exist to overcome the diurnal nature of the system's electrical output. At night time heat to drive the Stirling cycle can be derived from combustion of fossil fuels or biomass (a "hybridised" design). Alternatively, output can be stored in batteries, although this introduces new conversion inefficiencies.

Figure 2 The solar resource for CSP is sufficient in most of the developing world



Source: CSP Global Market Initiative[ii]. Key: Dark orange = excellent resource; pale yellow = adequate resource; green = insufficient resource.

1.3 Current state of the market

There are a very limited number of suppliers. While several companies have developed dish/Stirling systems over the years, only two appear poised to deploy the technology immediately on a commercial basis. These are Infinia, with its 3 kW PowerDish, and Stirling Energy Systems, with its 25 kW SunCatcher. Other companies (Wizard Power, Science Applications International Corporation, Schlaich Bergerman) appear to have products in development or pilot phase.

Commercial applications of dish/Stirling technology are either small-scale or pending. Stirling Energy Systems has secured contracts to install 800 MW capacity for grid-connected electricity generation in California, as well as 1.5 MW capacity for a town in Arizona. However, these projects have yet to be realised. Infinia has recently supplied units for all public buildings in the town of Belen, New Mexico. Other dish/Stirling installations, small-scale and pilot in nature, have been run for many years in a range of countries.

2 What is the rationale for an AMC?

2.1 Objectives

The rationale for an AMC supporting dish/Stirling CSP would rest on its future potential in meeting rural electrification objectives. The rationale can be broken down into the following component questions:

- Why support a particular technology rather than renewables in general?
- Why support dish/Stirling CSP rather than other technologies, particularly other CSP technologies?

There is a growing consensus that pro-poor rural electrification policies should be technology-neutral[1]. This prevents technologies which are unsuitable or not cost-effective from being chosen over more appropriate alternatives.

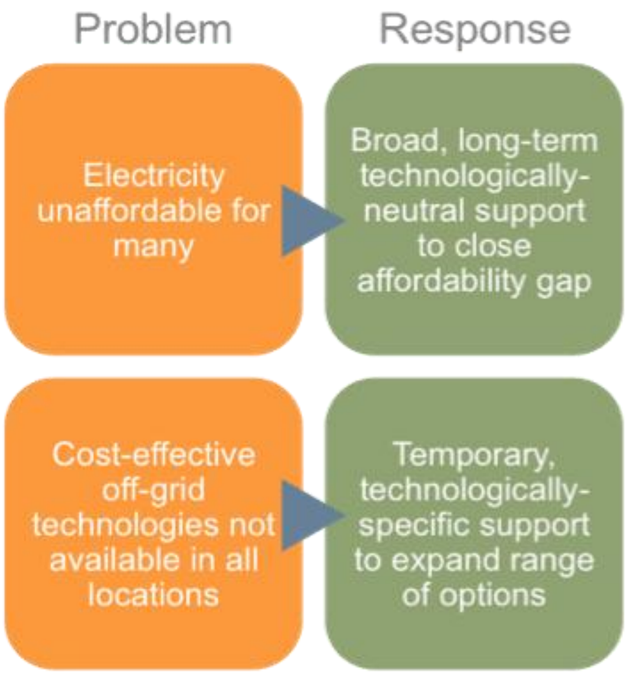
However, temporarily supporting a particular technology can bring it into the basket of cost-effective technologies which can be encouraged by more permanent, broader rural electrification policies. There may be some technologies which could play a useful role in extending rural electrification but which are currently held back by surmountable market barriers. Targeting support on removing these market barriers, and permanently improving the technology's cost-effectiveness, will allow the technology to move into the set of viable options in a way which business-as-usual renewables support will not. Whether technologically-specific support is justifiable therefore depends on policy objectives and the component of the problem trying to be solved

[1] World Bank (2008), *Designing Sustainable Off-Grid Rural Electrification Projects: Principles and Practices*, The World Bank, November 2008.

(Figure 3).

Extending the choice of viable technologies is worthwhile given the site-specific resource-dependency of renewables. Renewable technologies depend on the existence of a particular resource at a site: whether it be wind, water, sunshine or an appropriate biomass fuel being locally available. Extending the range of technologies increases the likelihood that a solution can be found for any given location. Although an alternative solar technology exists (photovoltaics) dish/Stirling CSP is likely to be cheaper (see Section 3.4).

Figure 3 Technologically-specific support may be justifiable for certain, well-defined policy objectives



Source: Vivid Economics

Dish/Stirling is the most suitable and well-established CSP technology for a decentralised context. The other established technologies, i.e. parabolic troughs, towers and Fresnel reflectors, are suitable either only for centralised power stations due to their use of steam turbine technology, or are available in a minimum size which is too big[2]. Modular units easily allow small increments in capacity as the population of the serviced area grows.

Dish/Stirling units are an appropriate size for a developing world village. Existing dish/Stirling systems range from 3-25 kW per unit. As discussed in Section 3.2, this would place the capacity, singly or in clusters, broadly in the range required by an Indian village (estimated at 0.675 kW per household for wealthier households).

Dish/Stirling CSP requires no supporting physical infrastructure, apart from access roads for maintenance. Unlike other CSP technologies, it does not require water, in short supply in many arid areas otherwise suitable for CSP technologies. Unlike diesel generators or biomass, it does not require a continual fuel supply which can be disrupted. It is also a technology with the prospect of relatively low barriers to entry as operations and maintenance activity requires limited skills – potentially it could be undertaken by car mechanics.

An AMC aiming to stimulate deployment of existing technologies is more justifiable than one focussing on technological innovation. There are many incremental technological advancements which the CSP industry foresees, such as higher absorbance coatings, improvements in reflectivity and durability of reflectors, and coatings for protection from corrosion and dust. However, none of these advances represents a breakthrough necessary for the technology to be successfully deployed. In addition, it would be very difficult to assess either the likelihood of them being achieved or the benefits which would result.

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[2] Other decentralised CSP technologies are available or in development. A 100 kW hybridised turbine, was launched in 2009 by Israeli company Aora. Sopogy's parabolic trough SopoNova product comes in a minimum size of 250 kW.

2.2 Compatibility with other policies

Compatibility with other policies requires ensuring both the additionality and complementarity of the AMC. The AMC will not be cost-effective if other policies are likely to (partially) achieve the same result. In addition, other policies with similar objectives should be complementary, for example by tackling related problems which the AMC cannot address, rather than rendering the AMC redundant. A review of other policies potentially affecting the technology is therefore key in order to make the case for the AMC.

2.2.1 Policy additionality

The main disadvantage of dish/Stirling CSP compared to other CSP technologies, that it does not allow thermal storage, is a disincentive to its use in grid-connected applications. Thermal storage is much more efficient than electrical storage, and can be used on a much larger scale. This is a major reason why policies to stimulate investment in grid-connected renewables will tend to encourage other CSP technologies.

Investment in dish/Stirling CSP will not be stimulated by existing feed-in tariffs. Feed-in tariffs for which solar thermal technologies are eligible, or which are aimed specifically at them, are in place in Spain, Algeria, France, Greece, Israel, Portugal and Italy. Tariffs range from 16-40 €c/kWh (23-58 US¢/kWh). The Spanish FIT has been extremely successful at stimulating interest in CSP. At least 2.1 GW of projects have been registered, seemingly all parabolic trough and power tower. In addition to thermal storage, these technologies are preferred because they are more proven, with more accumulated experience and lower cost.

An Indian solar feed-in tariff will be unlikely to support the technology. The Indian Government recently announced a tariff of 13.45 Rupees (US¢ 29.6) per kWh for grid-connected solar thermal technologies[3]. If the pattern followed in western countries is replicated, this will be more likely to stimulate the other

[3] CERC (2009), website of the Central Electricity Regulatory Commission

CSP technologies, reducing any spillover benefits for off-grid applications of dish/Stirling CSP from on-grid developments.

The market barriers facing grid-connected and decentralised applications are different. The cost and logistics of operation and maintenance (O&M) of a technology in a centralized grid-connected application can be well-known, but uncertainty over such factors in a decentralised context can act as a barrier to deployment. Such concerns will not be alleviated by policies stimulating large-scale grid-connected applications. In addition, small-scale renewables developers can face financing constraints, demand uncertainty and payment risks not faced by large-scale project developers, who sell to the grid rather than directly to consumers.

2.2.2 *Policy complementarity*

India is used in this section as an illustration of how policies may or may not be complementary within a given location.

Total rural electrification is already a policy aim of the Indian Government, with support mechanisms in place. The Rajiv Gandhi Grameen Vidyutikaran Yojana Scheme launched in 2005 aims to provide 24-hour access to electricity to all rural households[4]. Components of the programme include a 90% capital subsidy for rural electrification infrastructure (see next paragraph) and free of charge connection for households below the poverty line.

Clarification over whether existing support for rural electrification would cover solar thermal technologies would be required for AMC design. The above-mentioned 90% capital grant is available up to a limit of about 50,000-100,000 Rs ($1,100-$2,200) per kW. Small-scale solar thermal currently does not appear to be either explicitly eligible or ineligible[5]. This has two important

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[4] Ministry of Power (2005), *'Rajiv Gandhi Grameen Vidyutikaran Yojana Scheme for Rural Electricity Infrastructure & Household Electrification'*, scheme brochure

[5] MNRE (2009), Sanction of the President of India for implementation of the Remote Village Electrification Programme, F.No.15/1/2009-10/RVE, Ministry of New and Renewable Energy

implications. First, a grant would reduce the payment needed from AMC funds for projects to be profitable, and would help them stretch further; however, it might be decided that AMC-supported projects would be ineligible for grant support. Second, without inclusion under existing support, and in the absence of an AMC, a market for the technology would be even more unlikely to emerge spontaneously due to competition from grant-funded alternatives.

The Indian government may be supportive of interventions to bring down the cost of dish/Stirling systems. India's recent major solar energy policy statement, the Jawaharlal Nehru National Solar Mission, suggests loans and 30% capital subsidies for "innovative applications" of solar energy will be considered. Unspecified devices similar to dish/Stirling systems "would still require interventions to bring down costs", but are to be encouraged[6].

Policies to support solar thermal manufacturing may be considered in future. Policies announced in the Solar Mission to support PV manufacturing include zero import duty on capital equipment and raw materials, and priority low interest loans. According to the document, "an incentive package … could be considered for setting up manufacturing plants for solar thermal systems/ devices and components".[7]

14th July 2009

[6] Government of India (2009), *Jawaharlal Nehru National Solar Mission Towards Building Solar India*, policy document released 23/11/09

[7] Government of India (2009) *op. cit*

3 What is the potential market for the product?

This section considers the potential size of the market for dish/Stirling CSP. An assessment of this sort both to calibrate the design of the AMC and also to understand whether the market can be self-sustaining after the AMC support is withdrawn. It uses Rajasthan as an illustrative location. However, data is extremely limited for most of these factors, allowing only a very preliminary assessment.

Demand for off-grid electricity (OGE) in general will be determined by:

- the number of potential consumers
- the electrical output they require, in turn determined by the uses to which the electricity will be put
- the value to consumers of the benefit the electricity provides, measured by their willingness-to-pay (and dependent on their income level)

In addition, the market for a particular technology will be determined by:

- the cost compared with substitutes (both other decentralised technologies and grid connection)
- availability and constancy of renewable or fossil fuel resources

Sub-sections 3.1 to 3.5 cover each of these factors in turn with a summary provided in sub-section 3.6. Sub-section 3.7 considers the potential sustainability of the market after the AMC support has been withdrawn.

3.1 The number of potential consumers

Statistics on the number of unelectrified villages in India are variable. Separate data from the Rajasthan Department of Energy and the Central Electricity Authority suggest that there are 2,000-12,000 unelectrified rural villages in Rajasthan, corresponding to an electrification rate of 70-95%.

Even in villages that are electrified, not all households will receive electricity. It is estimated that 34-43% of households in Rajasthan overall do not have an electricity connection[8], while the 2001 Census placed 66% of rural households (24 million) as without electricity[9], although given the policy attention rural electrification has received this number may have declined since.

Household rural electrification rates are not the only factor determining the potential number of users. Many connected to the grid in rural Rajasthan complain of weak voltage and frequent power cuts. It has been suggested that decentralised renewables could be used to improve supply even in grid-connected villages.[10]

3.2 Electrical output

The output required by the smallest, poorest hamlets, primarily concerned with household lighting, are low. Indian government policy suggests that electrification technologies should be able to provide a minimum 'lifeline' power of at least 1 kWh per household per day[11]. Assuming this was spread between six hours in the evening, for a hamlet of 20 households this would

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[8] Governance Knowledge Website (indiagovernance.gov.in), an Indian Government website.

[9] Rural Electrification Corporation website (recindia.nic.in/), a state-owned company.

[10] Chaurey, A., Ranganathan, M. and Mohanty, P. (2004), 'Electricity access for geographically disadvantaged rural communities — technology and policy insights', *Energy Policy* **32**:1693-1705

[11] Ministry of Power (2006), Rural Electrification Policy Extraordinary Part-I Section-1, Gazette of India, 23rd August 2006 No.44/26/05-RE (Vol-II)

equate to about 3.3 kW peak generation capacity required. This is small for a mini-grid system and might be more appropriately met though household-level solar PV.

Larger villages with a wider range of applications require systems capable of peak electrical loads in the tens to hundreds of kilowatts. Nouni et al.[12] estimate the average per household peak electrical load for a relatively well-off Indian rural village, where householders have appliances such as fans, refrigerators and televisions, to be about 0.675 kW. Use of electricity for agricultural and commercial applications, such as water pumping and milling would also increase load requirements. Mini-grids using micro-hydro, biomass gasifiers and diesel generators tend to be in the range of 5-100 kW[13].

Dish/Stirling CSP is at the appropriate scale for the electrical output needs of Indian rural villages. The closest-to-market units are available in sizes of 3 or 25 kW. This suggests that they could be used either singly or in clusters of a few to a few dozen units. Clusters of smaller units may be preferred to avoid reliance on a single unit at risk of mechanical failure.

3.3 Willingess-to-pay and income

The willingness to pay (WTP) for electricity of Indian rural households is estimated by available studies at around 5-20 Rs/kWh (10-44 US¢/kWh). There is both anecdotal and empirical evidence to suggest that this level of stated willingness to pay is matched by real payments to operators of diesel generators and mini-grids. Despite this anecdotal corroboration, it should be noted that these studies are either are a decade or more old[14], do not fully

[12] Nouni, M.R., Mullick, S.C. and Kandpal, T.C. (2009), 'Providing electricity access to remote areas in India: niche areas for decentralised electricity supply', *Renewable Energy* **34**:430-434

[13] Nouni et al. (2009) *Op cit.* and NERA (2010), '*Scaling up Renewable Energy in India: Design of a Fund to Support Pro-Poor, Off-Grid Renewables'*, interim report for the Foreign and Commonwealth Office and the Department for International Development, NERA Economic Consulting

[14] The most frequently cited and comprehensive study of 5,000 households across six states uses

measure WTP for electricity[15], or are for a very small number of households[16].

Only small amounts of consumption at a low tariff will be affordable for many households. Indian rural households typically spend 10% of their income on energy, but most of this is in heating and cooking, likely to use direct heat and not electricity[17]. Expenditure of a few (1-4%) percent of income on electricity would seem realistic. Data is available on the average state-wide per capita income in Rajasthan and typical per capita annual expenditure by a moderately poor household ($500[18] and $120[19] respectively); however data is unavailable on typical *per household* income and expenditure. Nevertheless, comparison of the cost of running appliances (Table 1) suggests that only low consumption applications at a low electricity tariff would be affordable for many households, given that even this modest use could potentially be costly compared to the per capita income/expenditure figures available. This

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survey data from 1996 (Barnes, D. F., Fitzgerald, K.B. and.Peskin, H.M. (2002), '*The Benefits of Rural Electrification in India: Implications for Education, Household Lighting, and Irrigation'*, Background Study for India Rural Access Strategy, World Bank). A further example, with data from 1997, is Bose, R.K. and Shukla, M. (2001), 'Electricity tariffs in India: an assessment of consumers' ability and willingness to pay in Gujarat', *Energy Policy* **29**(6):465-478.

[15] Mukhopadhyay, K. (2004), 'An assessment of a Biomass Gasification based Power Plant in the Sunderbans', *Biomass and Bioenergy* **27**:253-264.

[16] The study reported by Cust et al (2007) was based on interviews with 35 households. Cust, J., Singh, A. and Neuhoff, K. (2007), *'Rural Electrification in India: Economic and Institutional aspects of Renewables'*, Cambridge Working Papers in Economics 0763.

[17] Cust et al (2007), *op. cit.*

[18] World Bank (2006), *'Rajasthan: Closing the Development Gap'*, Poverty Reduction and Economic Management Unit, South Asia Region

[19] Derived from Gaiha, R., Shankar, S. and Jha, R. (2010), *'Targeting Accuracy of the NREG: Evidence from Rajasthan, Andhra Pradesh and Maharashtra'*, Australia South Asia Research Centre Working Paper 2010/03

suggests that any co-payment by beneficiaries (see Section 5.4) during the AMC should be low, and the cost of electricity from the technology once support is withdrawn (Section 3.6.2) should also be at the lower end of the putative WTP range.

Table 1 Running appliances may be unaffordable for many households

Household application	Annual cost at WTP range of 10-44 US¢/kWh
Two 60W bulbs on for six hours every evening[1]	$26-116
As above + 75W ceiling fan running for 8 hours a day + 45W TV running 2 hours a day	$51-226

Source: Vivid Economics calculations based on WTP and household income statistics from Cust et al (2007) *op. cit.* and Gaiha et al, *op. cit.* [1] Note that this is less than the 'lifeline' figure of 1 kWh per day.

3.4 The cost of substitutes

3.4.1 Grid connection

Whether grid connection is more cost-effective than installing a mini-grid depends on distance from the grid, terrain, peak load and load factor[20]. It is also important to acknowledge that whether or not a village has a grid connection is not based entirely on the logic of cost-effectiveness, but also on political decisions and restrictions in protected areas[21].

Data is unavailable to assess how many villages in Rajasthan are in a given distance band from the grid, which would allow a cost comparison for a 'typical' unelectrified village. However, it is possible to gain an understanding

[20] This is the proportion of the output which the electricity infrastructure is capable of supplying which is actually consumed.

[21] Chaury et al (2004) *op. cit.*

of how the potential market for OGE technologies changes with their cost compared to grid connection. Figure 4a uses data on grid connection cost in India[22] to compare the range of applications, varying by load, distance, terrain and peak output, which are cost-competitive with grid connection at a levelised cost of electricity (LCE) of 25 US¢/kWh[23] (11.4 Rs). The figures show the frontier on or below which off-grid generation is cost-competitive. The OGE technology would be cost-competitive with grid connection in a small number of circumstances, mostly restricted to hilly areas and low load, more remote villages in flatter areas.

Halving the levelised cost makes the technology cost-competitive in a much broader range of contexts. At 12.5 US¢/kWh (Figure 4b) the OGE technology is competitive in a wider range of less remote villages with higher electricity demand on flatter terrain, including some which are quite close to the grid (5-10km). This suggests that the potential to bring the cost of dish/Stirling electricity down would be crucial to making a case that it could be a widely-applicable alternative to grid extension.

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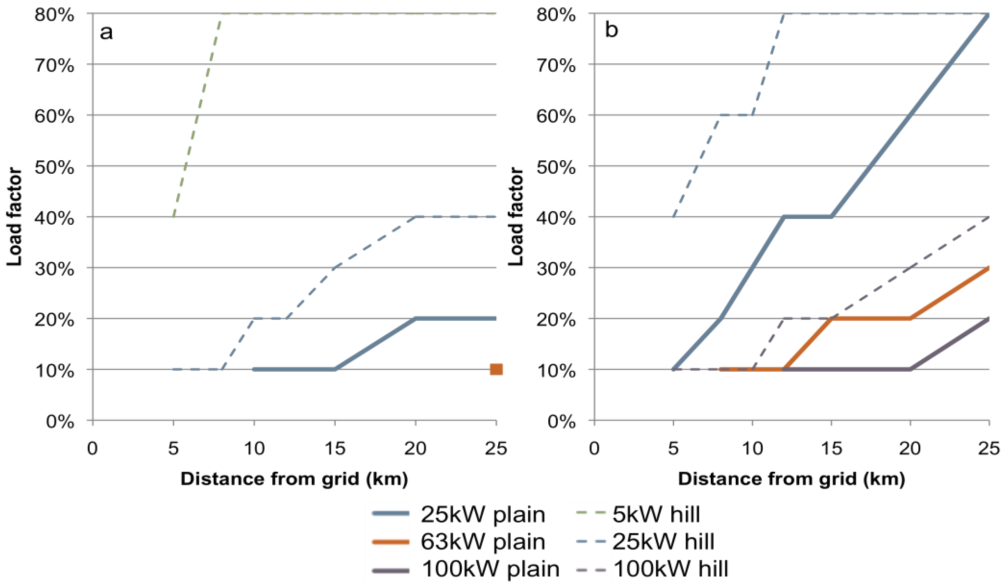
[22] Source: Nouni et al (2009), *op. cit.*

[23] This figure is the mid-point of the Indian estimate for a decentralised, with storage context application, shown in Figure 5.

Figure 4 Halving the levelised cost of off-grid electricity makes it cost-competitive with grid connection in a wider set of contexts



Source: Vivid Economics using data from Nouni et al (2009)

3.4.2 Other decentralised technologies

Available cost estimates for the deployment of dish/Stirling CSP in India are old and necessarily pre-date commercial application. They tend to be based on field trials. By contrast, cost data relating to other decentralised technologies can be drawn from operational experience.

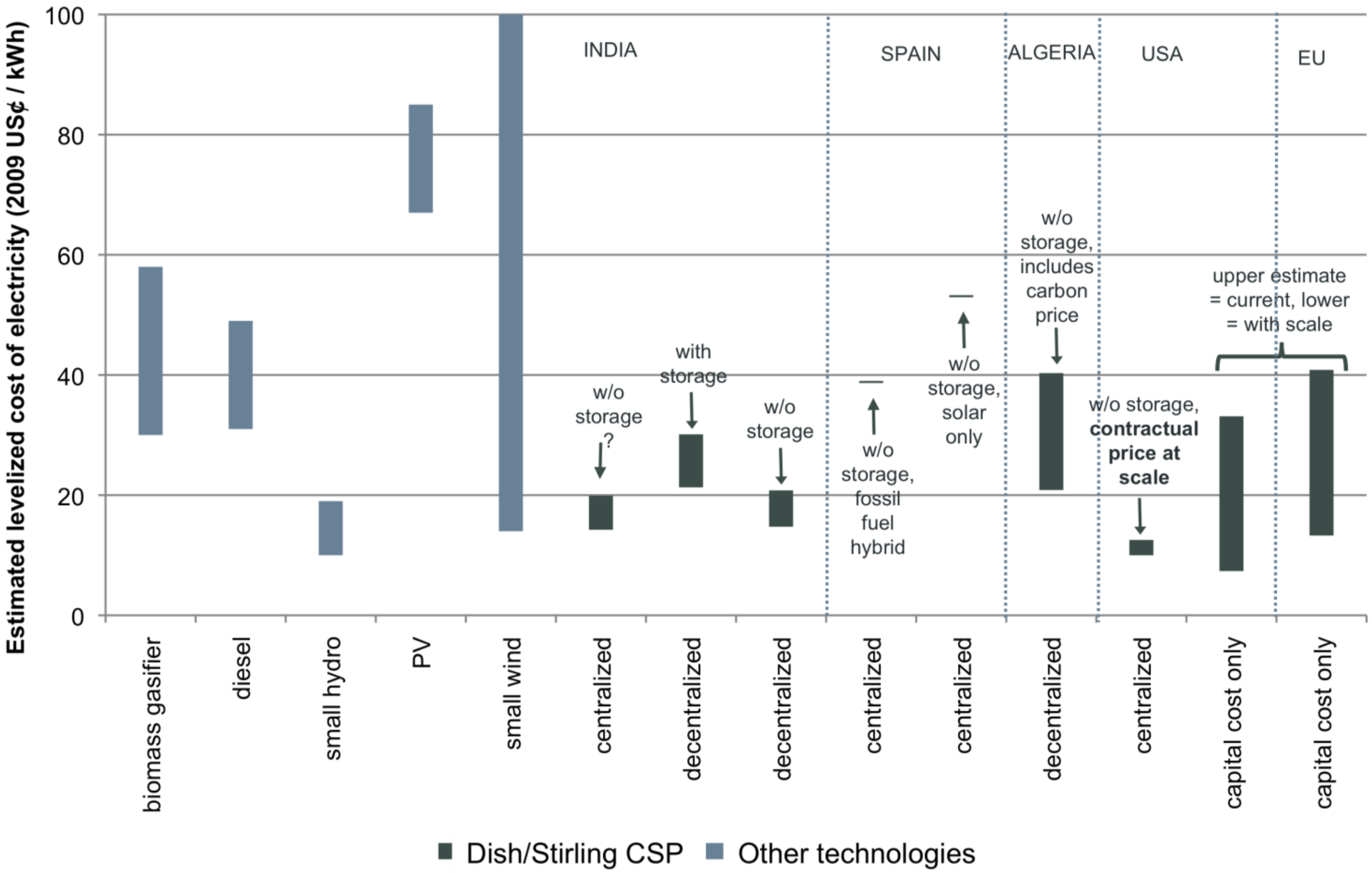
These caveats aside, dish/Stirling CSP appears either to be currently, or to have the potential to be, cost-competitive with other OGE technologies. Figure 5 compares ranges of estimates of the levelised cost of electricity for dish/Stirling CSP from four countries (including India) with estimates for other technologies specific to India, the latter also presented in Table 2. Dish/Stirling CSP appears to be cheaper than biomass, diesel and PV, although the costs of PV have been declining and may fall further. Wind is cheaper in some, but not all, cases, while hydro is likely to be consistently cheaper, given a suitable resource. Note that the figure does not include one commonly-used competitor, kerosene, as it is not a perfect substitute, suitable only for lighting.

Table 2 Dish/Stirling CSP is comparable to or cheaper than alternatives

Technology	Levelised cost of electricity in Indian off-grid context (2009 US¢ / kWh)
Dish/Stirling CSP with storage	21-30
Biomass gasifier	30-58
Diesel	31-49
Small hydro	10-19
Photovoltaic	67-85
Small wind	14-100

Source: Nouni (2009) and Beerbaum and Weinrebe (2000)

Figure 5 Estimates suggest that dish/Stirling CSP may be cost-competitive with other off-grid technologies in India, but are mostly based on field trials rather than practical experience



Source: Beerbaum and Weinrebe (2000); Pitz-Paal et al. (2005); Abbas et al. (2009); BusinessWeek (2005); Staley et al. (2009); Nouni et al. (2009).[iii]

The Indian dish/Stirling CSP cost estimates are consistent with manufacturing volumes slightly higher than at present. Current capital costs are very high due to extremely low production volumes. It has been suggested that building around 40 units concurrently could reduce unit costs by 40%, with real manufacture at scale reducing costs by up to 70-80%[24]. The estimates presented imply a unit capital cost at the intermediate stage of manufacture. They are therefore indicative of early-to-mid stage market development in India, rather than either tentative pilots or a mass market.

Use of storage, fossil fuel hybridisation, insolation and whether the application is on or off-grid all influence cost estimates. Electrical storage increases the LCE of decentralised dish/Stirling CSP but allows a wider set of applications and so would be likely to improve demand. LCE estimates for Spain are higher than those for India or Algeria due to the lesser solar resource.

3.5 Availability and constancy of renewable or fossil fuel resources

While CSP is highly dependent on insolation rate, almost all small-scale renewable OGE technologies rely on the presence of suitable resources. Cheaper OGE technologies, such as micro-hydro and wind, are highly dependent on suitable water or wind resources being available, with prospects for hydro diminishing in drier and flatter areas. Within a suitable climatic zone, solar energy is likely to be a more reliably widespread resource than wind or water with suitable head and flow.

The diurnal nature of solar power suggests that electrical storage or hybridisation would be essential. Apart from in niche agricultural applications, the electricity generated would be required in the evening for lighting and other household uses; otherwise the potential market and

[24] BusinessWeek (2005), *'Power from the Sunbaked Desert'*, 12th September 2005; Renewable Energy Focus (2008), *'CSP: dish projects inch forward'*, Renewable Energy Focus July/August 2008

corresponding WTP would be very much diminished. Twenty-four hour access to electricity is also an aim of Indian Government rural electrification policy. Hybridisation, using fossil fuel or biomass combustion as the heat source driving the Stirling engine at night time, is an alternative to electrical storage. Either alternative would add to cost, although with regard to hybridisation in a developing world context, the magnitude of this impact is unclear. [25]

Inclusion of storage requires the cost of the technology to be brought down in order to meet WTP of poorer households. The Indian estimates suggest that storage would increase levelized cost by about 42%, from 12-17 US¢/kWh without storage, to 17-24 US¢/kWh with it. This is lower than WTP estimates for many households, but higher than WTP estimates for the poorest. The rest of the case study assumes that storage is a necessity, despite the higher price it entails.

3.6 Potential market summary

A tentative household-based estimate suggests that the potential untapped market for electricity in rural Rajasthan could be in the region of $900 million per annum. This assumes that 24 million unserved rural households would pay 10 US¢/kWh[26] for 1 kWh per day. In reality, a proportion of these households would not be able to afford this tariff, while others would wish to consume much more than 1 kWh per day, and would be willing to pay more for it. Dedicated market research would be required for a more accurate estimate.

The proportion of the potential rural market for electricity which could be met most cost-effectively through CSP is unknown. Less remote unelectrified areas could be more cost-effectively served through a grid connection; sites with suitable wind and (less likely in desertified Rajasthan) water resources

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[25] While fossil fuel hybridisation reduces the LCE in a centralised developed world cases, the same is not possible in decentralised developing world cases due to the high costs of diesel generation.

[26] The willingness-to-pay estimate for the least well-off households in Cust et al *op. cit.*

could benefit more from these alternatives; while hamlets with extremely low loads may be better served through PV solar homes systems. It is possible that there are settlements not meeting any of these criteria which would benefit from micro-CSP. If there are 2,000-10,000 unelectrified villages in Rajasthan, a conservative estimate would suggest that installations of a few hundred dish/Stirling units could be covered by an AMC.

3.7 Potential for long term sustainability

Long-term market sustainability appears possible for lower cost manufacturers. An illustrative 15 US¢/kWh long term target price is used here to test long-term sustainability. Estimates of potential capital cost reductions based on manufacturers' claims[27] (as already presented in Figure 5), combined with an approximate estimate of storage costs[28], suggests that such a target could be met for two existing products with O&M costs of 3-4 US¢/kWh annually. This is equivalent to about $1,630-2,300 per annum per unit, or about 33-45% of the annual wage for a skilled worker in India, which would seem a generous amount for O&M. However, this analysis suggests that such a target price could not be met by all technologies according to the cost estimates available (Figure 6).

The reduced long term levelized capital cost estimate assumes that financiers have gained familiarity and confidence in solar technologies. It has been reported that at present typical interest rates for solar projects in India are 13%[29]. An LCE of 15 US¢/kWh would not be possible at such high interest rates (Figure 6 uses a 7% interest rate). Therefore for long-term sustainability it would be vital that the AMC aims to reassure investors as well as operators and consumers.

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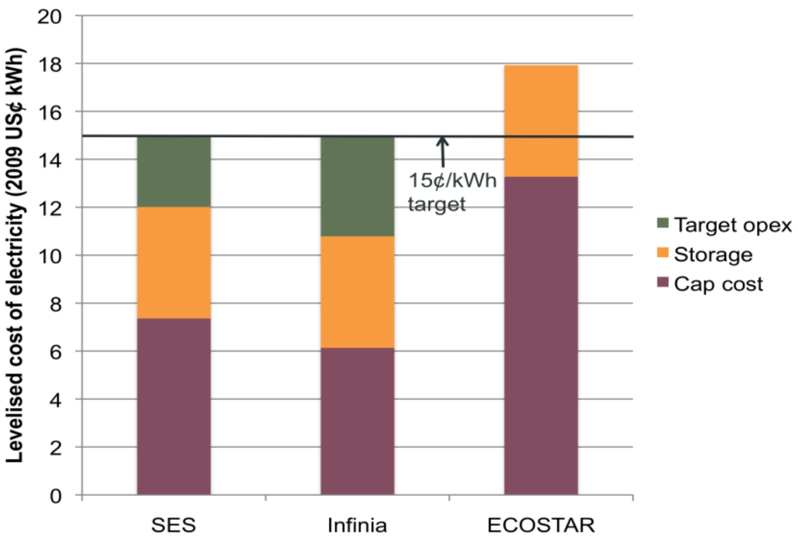
[27] BusinessWeek (2005), *op. cit.*; Renewable Energy Focus (2008), *op. cit.*; CNN (2009), *op. cit.*

[28] Derived from Beerbaum and Weinrebe, *op. cit.*

[29] Greentechmedia (2010), '*The India Solar Market: How Big and How Soon?'*, www.greentechmedia.com

Measures to improve access to finance of rural communities may also be important for long-term sustainability. There is a wealth of experience from rural electrification subsidy programmes that access to consumer finance is often a key component to ensuring their success, serving to smooth over seasonal fluctuations in income, improve affordability and reduce non-payment risks for operators[30].

Figure 6 Cost estimates suggest that a long term market price of 15 US¢/kWh would allow commercial viability for some products



Source: Renewable Energy Focus (2008), Pitz-Paal et al. (2005), CNN (2009),[iv] Beerbaum and Weinrebe (2000); Vivid Economics calculations

[30] IFC/GEF (2007), *Selling Solar: Lessons From More Than a Decade of IFC's experience*, International Finance Corporation; World Bank (2008), *op. cit.*

4 What are the current barriers to market development?

Potential market barriers in this case can be placed into two broad categories: those relating to comparative cost and those relating to risk and unfamiliarity:

— *Cost:* the cost of the technology may be high compared to alternatives or to potential customers' willingness to pay

— *Risk/unfamiliarity:* Suppliers and operators may be unsure of the logistical and economic feasibility of applying the technology off-grid. The technology may be yet to establish a reputation for reliable service, and consumers and investors may be deterred by the perception that it is unfamiliar and unproven.

Higher cost in comparison to alternatives is not a particular market barrier in a decentralised context. According to the data displayed in Figure 5, fossil fuel alternatives are not necessarily cheaper in decentralised applications. In addition, the cost of dish/Stirling systems is comparable to other renewables.

A lack of confidence over the feasibility of operating and maintaining units in a decentralised, developing world context is the main market barrier. At least one supplier does not yet view distributed applications as likely to be economic. Concerns over technological reputation mean that the extent of suppliers' involvement is highly unlikely to end at the point of sale in the short-to-medium term, increasing the investment of money and time required in order to enter any given market. The prospect of maintaining sparsely-distributed small clusters of units would add to concerns over logistical and economic viability.

Reliability is a concern which would need to be alleviated. Unlike solar PV, dish/Stirling systems contain moving parts which can fail or wear out. Shut down every evening increases wear and tear. In a mini-grid context, one module out of action would be a high proportion of generation capacity. Concerns over reliability would need to be alleviated through accumulated experience and assurance that O&M support can arrive quickly if required.

The technology would need to be proven in a decentralised context before it is likely to draw the level of interest from domestic investors, operators and customers required for a self-sustaining market. Investors currently lack precedents and physical or financial data against which to judge likely returns, while potential operators and customers are unaware of the technology's existence and benefits.

The AMC cannot necessarily tackle all market barriers. Lack of credit for end-users and small entrepreneurs is frequently cited as a market barrier to wider deployment of off-grid technologies[31]. Such additional barriers may need to be addressed by measures complementary to the AMC, such as concessional loans, although the provision of consumer credit by suppliers has been attempted in some renewables support programmes.

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[31] IFC/GEF (2007), *op. cit*; World Bank (2008), *op. cit.*

5 What are the considerations for AMC design?

5.1 Objectives

The over-arching objective for the AMC is to expand the range of technologies available for off-grid supply so that more people in developing countries can benefit from affordable access to electricity. In order to achieve this, the outcomes which the AMC would need to produce are a sufficiently low levelised cost of electricity produced by the technology and proven reliable operation in decentralised operations.

The main practical goal is to support a period of learning on the costs and logistics of installing and maintaining the systems in a decentralised context in a developing country. The costs and risks associated with O&M need to be reduced. The technology needs to be sufficiently proven, and its reputation sufficiently robust, to allow demand for the product to be maintained once support is withdrawn. Reliability needs to be improved, and evidence on expected performance provided to potential investors.

A long-term reduction in the capital cost can be expected to follow from deployment at scale. Significant capital cost reductions are thought possible through manufacture at scale (Figures 5 and 7). Stirling Energy Systems has claimed that manufacturing at scale would allow them to reduce the cost of their 25 kW SunCatcher unit by 70-80%[32]. A 2005 EU study suggested that a total cost reduction of 68% was achievable through a combination of mass

[32] BusinessWeek (2005) *op. cit.*, Renewable Energy Focus (2008) *op. cit.*

production and technological improvements[33]. However, the former reduction is due to come about due to SES's contracts for grid-connected applications in California. Whether capital cost reductions need be an explicit objective of the AMC therefore depends how certain it is that this will come to fruition, and whether a similar reduction can be expected from other suppliers.

The growth of private sector manufacturing capacity would be an additional objective for some host country governments. Prospects for private sector manufacturing capacity would depend on the business models the AMC was able to encourage (see Section 5.5) and the willingness of manufacturers to locate production facilities in host countries. India has an explicit policy objective of encouraging solar PV manufacturing, and may also express one for solar thermal in future[34]. The presence of an automotive sector in a host country is a good indicator that manufacture of dish/Stirling units could technically be located there, given similarities with the manufacture of car engines. Visibility of opportunity and the prospect of large-scale deployment would be key to any decision to locate manufacturing facilities in a developing country.

5.2 Geographical scope

In general, significant cost reductions would be expected with a more geographically widespread AMC. If capital cost reductions will follow from manufacture at scale and the potential market for the technology within any one country or region is limited, logic dictates that a large-scale international AMC would be most likely to bring down the cost. However, following the discussion above, it is not clear whether capital cost reductions needs to be an objective of the AMC.

Single-country programmes may be sufficient to accelerate learning on

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33 Pitz-Paal, R., Dersch, J. and Milow, B. (2005), *ECOSTAR: European Concentrated Solar Thermal Road-Mapping: Road Map Document*, report for the European Commission

34 Government of India (2009), *op. cit.*

O&M. For example, while there are key uncertainties about potential demand in Rajasthan, the approximate figures presented in Section 3 suggest that sales could be of a few hundred units. This may be sufficient to accelerate learning on O&M, for which it would also be preferable to have a sufficient geographical density of units.

A provisional series of single-country programmes to provide both potential for volume and geographical density, as well as to incorporate lessons from previous stages, might be the most desirable approach.

5.3 Does the AMC administrator purchase, mandate or provide incentives?

The arguments for an AMC which incentivises purchase by private actors are strong. The administrator has limited information about where generation through dish/Stirling units could be deployed in order to deliver genuine benefit, be cost-effective compared to alternatives and see sustained use in the long term. Avoiding waste is the principal reason why approaches which make it easier for beneficiaries to purchase goods and services which they value have gained favour in development circles over gifting.

The rationale for co-payment is strengthened by the properties of the target product and its market. Firstly, the AMC is designed to support a product for which there are plenty of direct substitutes. Co-payment decreases the likelihood that the technology will be deployed in favour of more cost-effective alternatives, given that consumers will opt for the cheapest, most suitable option. Secondly, the product generates an ongoing service rather than offering a one-off benefit. Therefore, it risks being stranded and falling into disuse if it is not deployed where it is genuinely valued, as signalled through co-payment. Co-payment has been demonstrated by international experience as a practical, realistic and standard component of rural electrification support mechanisms[35].

Co-payment would takes the form of an electricity tariff paid by end users to

[35] IFC/GEF (2007), *op. cit*; World Bank (2008), *op. cit.*

an operator, and a subsidy to producers allowing them to offer electricity to customers at a competitive or below-cost price.

The risk of theft and non-payment, while real, is not sufficient to undermine the principle of co-payment. Theft and non-payment are known to be problems in the Indian power sector[36], potentially posing problems for a co-payment mechanism. However, it is also often observed that decentralised applications tend to reduce theft and collection risks through community peer pressure and increased chance of detection[37]. Accurate metering can also help counter these problems.

Mandating purchase of units on the part of mini-grid operators would weaken their incentives. For completeness, a further alternative would be to oblige mini-grid operators to include dish/Stirling units in a certain proportion of their projects. This would place the costs and risks associated with gaining familiarity with this new technology on operators. As a result, mini-grid projects in general would appear less attractive to operators, and the desired scale of installations would be unlikely to materialise.

5.4 Business models

The design of the AMC depends on the assumptions that are made about the business models it will incentivise. This is particularly the case where the target product generates an ongoing flow of services, as electricity generation technologies do.

The key differences between business models in this case is the question of who undertakes maintenance and whether maintenance is separated from supply. A simple retail approach, where end-users pay for units to be installed

[36] World Bank (2004), *Rural Access to Electricity: Strategy Options for India*, Discussion Paper, South Asia Energy and Infrastructure Unit; Bhatia, B. and Gulati, M. (2004), '*Reforming the Power Sector: Controlling Electricity Theft and Improving Revenue'*, World Bank Public Policy Journal Viewpoint no. 272.

[37] World Bank (2004), *op. cit.*

(for example via a user association) without a maintenance contract, does not appear practical in the case of micro-CSP given: (i) the need for ongoing maintenance and current concerns over reliability (although this may be a lesser concern in the future); and (ii) the large capital outlay involved (tens of thousands of dollars for larger units even with subsidy). The most likely business models are therefore:

- Dish/Stirling manufacturers provide an entire service, supplying, installing and operating units ('supplier model')
- Dish/Stirling manufacturers franchise local partners to install and operate units ('franchise model')
- Energy service companies purchase units from manufacturers and install and operate them ('ESCO model')

At least one major dish/Stirling CSP supplier is currently unwilling to separate installation and O&M from unit sales, inhibiting the franchise and ESCO models. They consider the reputational risk to their product and the technology as a whole to be too great if other parties, who may be less competent or have a lesser stake in ensuring reliable performance, undertake maintenance. However, the supplier model would restrict competition and may not be desirable to the AMC administrator for that reason. Which of these models is practicable would therefore be tested during both negotiation with the industry and early stage market development, and it may be that a mixture of models would result.

Payment recipients differ under the supplier and ESCO models. Under the ESCO model, the ESCOs would receive the AMC payment, allowing them to purchase dish/Stirling units when they would not otherwise be cost-effective. Under the supplier model, manufacturers would receive the payments.

5.5 $ per what?

Different incentives are introduced by the form the payment takes. The three options examined are to offer a price per:

- kW peak capacity installed (a per unit payment would not be able to differentiate the very different sizes at which units are available)
- kWh of electricity generated
- customer (household, village or connection)

A per kW capacity installed price is more transparent for operators. The capital cost of the units is the greatest component of cost. Suppliers or ESCOs would know exactly how much subsidy they would receive per unit installed, and therefore what proportion of their largest cost driver is covered. The overall amount of support to be received in the other approaches would be more obscure. Subsidising upfront capital costs would also alleviate financing problems for ESCOs.

A per kW capacity installed payment is simpler for the AMC administrator. As payments are one-off, it would be easier to monitor the financial commitments of the AMC and stick to its budget. A payment based on output would make decisions on whether supporting successive installations is affordable more difficult. In addition, it would require metering arrangements and an audit trail proving the amounts generated.

However, a per kW capacity installed payment weakens incentives for ongoing supply. The major disadvantage of a capacity-based payment is that incentives for a good quality, ongoing service are based on customer revenues alone. An output-based payment incentivises a stronger ongoing commitment from operators. If customers undergo periods of financial stress or more commercially attractive customers are found elsewhere, the ESCO or supplier are less likely to deprioritise AMC beneficiaries. This possibility may be further mitigated through good contract design and monitoring on the part of the AMC administrator.

Capacity-based payments have been criticised in India. Concerns have been raised that capacity-based payments have lead in the past to installations which are larger than required, under-utilised or poorly situated[38]. They are further criticised for giving poorly performing installations as much support as productive ones. Given this experience it would be particularly important, should per kW payments be considered, that they be designed to ensure that customer payment and satisfaction are requisite for profitability.

Per connection and per kWh payments offer incentives to sign up different types of customers. A per connection payment system would incentivise operators to sign up as many users as possible, rather than particularly seek out users whose businesses could benefit from access to electricity. A per kWh payment would be more likely to incentivise supply to heavier load applications such as agriculture or light commercial uses, but might neglect poorer households.

Visibility of electricity prices is crucial. Even with a capacity or connection-based payment, operators would need to have a firm idea of the prices they might receive from recipients.

5.6 Pricing mechanism and negotiation

The main choice in pricing mechanism lies in setting a uniform price[39] administratively or devising a competitive bidding mechanism. Under a uniform price, the AMC administrator estimates what the appropriate level of support is and pays each applicant the same per unit amount. Under a competitive bidding mechanism, the administrator invites interested parties to participate in an auction or submit sealed bids for the amounts they are willing to supply at a particular price. Depending on bid mechanism design, applicants

[38] NERA (2010), *op. cit.*

[39] Note that a uniform per unit subsidy, rather than a certain uniform price, would not fit the strict definition of an AMC set out in Section 2.2 of the main report. The uniform price AMC discussed here would give suppliers a visible guaranteed price, with the subsidy amount representing the difference between this price and any co-payment made by consumers, which may vary between income groups. Despite the attractiveness of a fixed price, as discussed in the main report, it is acknowledged that a per unit subsidy may have practical advantages.

may receive different amounts of support per unit. Payments under both mechanisms can change over time in order to reflect cost reductions that have been achieved.

Well-designed competitive bidding mechanisms can reveal information on the "willingess to accept" of suppliers and reduce rents. Although significant uncertainties may remain, companies are likely to have a much better idea of their costs and capacities than the AMC administrator. By being invited to state the prices they are willing to accept, suppliers reveal information to the administrator on how much they need to pay to achieve a particular result. Two examples of competitive bid mechanisms are:

- Sealed bid, where companies would bid the quantity they can commit to for a particular price, and a suggested co-payment as well as, if necessary, qualitative characteristics of their bid. Bids would then be accepted up to a target quantity.
- Descending clock auction, where companies bid the quantity they can supply for a series of incrementally decreasing prices. As prices decrease, less efficient suppliers drop out. The price drops until the quantity desired by the administrator is achieved, and the same price is paid to all remaining bidders. The primary disadvantage of this method is that it does not allow qualitative aspects of bids to be assessed. However, it is transparent and reveals greater information on the quantities companies are willing to supply at different prices.

Figure 7 illustrates the outcome of a bidding mechanism with operators receiving varying amounts. The shaded area represents the total amount paid out by the AMC, while the shaded area above the black line represents the rents paid to suppliers or operators.[40]

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[40] In this example, there is also a segment of the market, $Q_{w/oAMC}$ – 0, that would be sold at a higher, unsupported price. This discrimination between the supported and unsupported segments of the market might be achieved, for instance, by only making the AMC available to support

The potential low number of suppliers and the risks of the technology imply that bilateral negotiations might be preferred. Some auction mechanisms are inadvisable with as few as two bidders. With few suppliers, bidders may be able to anticipate the bids of their competitors, making the auction uncompetitive. Great uncertainty over potential profitability may make suppliers unwilling to commit to large quantities initially. In addition, as discussed in Section 5.4, it is likely that some suppliers would be willing to accept certain business models that others would not. Bilateral negotiations are feasible with a low number of suppliers, and would be able to better ascertain the concerns of suppliers and the speeds at which they are willing to progress.

The pricing mechanism should also consider what end-users will pay. The agreed level of co-payment by beneficiaries will influence the size of the market; the lower the payment, the more low income consumers will be able to benefit. The AMC could be designed so that all beneficiaries pay the same price, or so that those with higher income pay slightly more. Figure 7 illustrates an AMC with a uniform price faced by those consumers eligible for support (and a higher, uniform, price paid by those who do not qualify for support).

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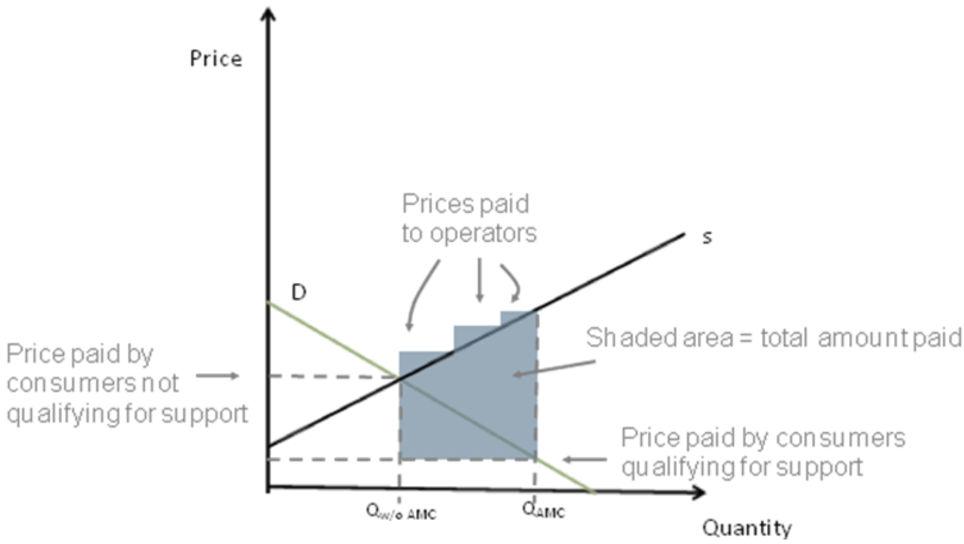
supply in particularly poor/rural locations.

Figure 7 With careful design, the bulk of the AMC budget should result in high welfare gains for consumers, not suppliers



Source: Vivid Economics

Support could vary as a function of insolation rates. Given the lower economic viability of CSP in lower insolation rate areas, a decision would need to be made over whether to restrict the geographical range with relatively invariant support, or to make concessions for applications in areas with a lesser resource. However, unless calibrated very carefully, the latter approach could provide an incentive to install the technology in inefficient locations.

5.7 Accommodating cost uncertainty

The proposed AMC would require producers to commit to a fixed price. As indicated in the theory paper, there are potential problems for producers in reducing price flexibility when there is uncertainty over costs. This is pertinent in the context of micro-CSP which, as a relatively immature technology, is likely to be exposed to cost uncertainty. This uncertainty is indicated by the wide difference between current and expected future capital costs, as well highly uncertain O&M costs.

However, there are practical advantages in using a price AMC in this context.

As discussed earlier there are advantages in making the AMC support contingent on an indication that consumers are willing to pay a certain (albeit subsidised) price for a product. Designing an AMC which makes use of co-payments to signal real consumer demand means that it is difficult to guarantee a quantity. Therefore, in a situation in which the AMC requires the explicit use of subsidy to account for affordability constraints, it is more practical to achieve this by altering the prices faced by consumers.

The AMC can be designed in a way to minimise the risk of cost uncertainty that producers face. One option would be to hold the auctions (or otherwise provide support) sequentially. This would mean that the experience gained from earlier periods on costs (and demand) could inform the level of support required in latter rounds. This could be further refined by providing support in early periods for reasonably small tranches of supply and only increasing the size of the support/supply commitment when producers have developed a greater understanding of their costs.

5.8 Conditions

Adding conditions to the AMC allow its effects to be enhanced and makes it more likely to leave a lasting legacy. Support could be made conditional along the following lines:

- *Reliability standards*: the technology must have achieved a certain reliability for the post-support market, for example a target empirically-demonstrated O&M cost, or a maximum permitted probability of breakdown within a year;
- *Target LCE*: in analogy with the vaccine AMC, the product must be available at a target LCE for a given number of years after support. This LCE might be reflected in a formula or protocol created by AMC administrators, or under a per kWh payment it could be reflected in the price they eventually received;
- *Target capital cost*: a target cost per kW of capacity could be set, although this would not incentivise product design for low O&M costs.

5.9 Eligible technologies

It should be considered whether dish/Stirling systems without electrical storage and hybridised systems should be eligible for support. Systems without storage will be less useful for the average consumer but may find niche applications. It should be foreseen that fossil fuel hybridisation might place the objectives of donors and end-users in conflict. However, it might also be the case that a hybridised system would generate a net carbon emissions saving compared to grid-connection.

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