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A Multiplier Approach to Power Generation for Remote Tropical Regions

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A Multiplier Approach to Power Generation for Remote Tropical Regions

John C. Edmunds [α] & Charles Winrich [σ]

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I. OVERVIEW: IN SEARCH OF A POLICY FOR REMOTE TROPICAL REGIONS

Prosperity, when it comes to a country, usually shows up first in the big cities. Later it spreads to remote, far-flung parts of the country. Some of these peripheral territories receive the friendly winds of prosperity only much later, and some are so far away from the action that they never really participate. Those are regions that, for lack of infrastructure, institutions, or rapid communications, cannot put into effect the full range of economic policies that national governments can apply. Those regions are constrained to adopting local remedies, and cannot depend on extensive, well-functioning links to large cities or major avenues of trade. They have to accept macroeconomic realities, such as the exchange rate of the national currency and the (probably low) market price of their export goods, if they have any exports. These areas cover as much as 5% of the Earth's total land area, and are home to as much as 1% of the Earth's population[1].

Remote areas, and especially islands with low population density, are suitable for study because they allow researchers to see a simple, stripped-down version of an economy, in plain view without the layers of complexity and the distortions that bombard the observer who studies the economy of a modern metropolis. Thinly populated islands at the far reaches of a nation's transport system have to have simple economies because they do not have enough contact with metropolitan zones to play a supporting role in the complex metropolitan economy.

This attempt to examine simple, isolated regional economies is a modern version of an analytical approach that has a long pedigree in the history of economic thought. As the theories of economic development and human decision-making were developed, it was helpful to conceptualize an economy for an isolated region, especially an island. In particular, economists long debated the Robinson Crusoe economy, in which a single individual inhabits an island that has no trade with the outside world and never receives visitors. This single-person economy is a useful setting to discuss consumer preferences, production possibilities, and tradeoffs between production of one good versus another. In the original formulation of this parable, trade with other islands was impossible and telecommunications did not exist. In the updated version presented here, the remote region is not completely isolated, and has more than one inhabitant, but is still thinly populated and does not have much commerce with less remote regions. Trade is possible, but on disadvantageous terms, and so the remote region only exports goods that are exceptionally valuable, or which the remote region can produce with some absolute or comparative advantage. The remote region import goods, but its financial resources are severely limited, so it imports only necessities and a scant few luxuries.

Insights gained by studying simple systems can sometimes be applied successfully in more complex systems. The policies recommended here can be applied effectively in other remote areas, but would not necessarily apply in urban or thickly settled regions. Nevertheless, the discussion here might trigger constructive debate about economic systems in more thickly populated regions.

II. STARTING ASSUMPTIONS

To begin, assume that a natural disaster has wiped out all the buildings, production facilities, and installed equipment in the remote region. The recent

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[1] We use low estimates for the tropical lands where the policy described here might apply. As much as 40% of the Earth's surface is in the tropics, but much of that surface is covered by oceans, and the tropical land area includes dry zones and heavily populated zones. The policy described here would not apply in arid or heavily populated zones.

Typhoon Haiyan delivered a blow to the Philippines, and left several remote islands and peninsulas completely in ruins. It set those isolated places back completely. The local populations needed humanitarian relief, and struggled to rebuild their lives. They needed to rebuild their dwellings, their infrastructure, their production of goods and services, and their trade with the outside world.

The central question of this investigation is what changes those remote regions should make in their economic systems as they recover and rebuild. Before the natural disaster, their economies were in an equilibrium that provided the bare necessities of life but not much more. These remote regions suffered outmigration and could not attract immigration, except seasonal workers who came to help with harvests but usually did not stay.

These remote regions are unable to influence macroeconomic policies, and cannot improve their bargaining power in long-distance trade. They have access to cell phones and the Internet, and can import equipment and technology from outside suppliers. They can borrow money from lenders outside the remote region, but need to be able to repay the loans. They pay taxes to the national government, but the taxes are low, and they receive little from the national government. They have exports of traditional commodities, including coconut oil and meal, cane sugar, and hemp fiber. They receive a trickle of tourists seeking adventure and solitude. But their revenue from exports is low and unstable.

We chose the Philippines for examples of remote tropical regions because that country has many remote, thinly populated islands. Many of these are only serviced by ferries departing from more populous islands. Indonesia also has many thinly populated islands, scattered over thousands of kilometers of ocean, and in other parts of the world there are many similarly remote islands, or remote regions, so the policies discussed here will potentially be applicable in many parts of the world.

The Philippine examples we chose are Dinagat Island (population 126,000 before the typhoon, land area 1036 square kilometers). Dinagat Island is close to Mindanao, and faces the Pacific, with no islands to buffer it from the typhoon's force. In the past it had mines and now has some facilities for tourists. Guiuan Town, our other choice, is at the end of a peninsula that is part of Samar Island, adjacent to Leyte Island. Guiuan Town also includes islands facing the Pacific that are strung out from the end of the peninsula. Magellan is thought to have landed on one of those islands, but they are not popular tourist attractions. Guiuan Town has an airport and is connected by road to Tacloban City. The road is 89 kilometers and runs along the coast. Before the typhoon the driving time was given as two and a half hours. The islands beyond Guiuan Town are not connected by causeways and do not have regular ferry service. Population of Guiuan was 47,000 before the typhoon and its area, including the islands, is 175 square kilometers. Guiuan Town therefore includes areas that are extremely remote. Both Dinagat Island and Guiuan Town are remote enough so that policies discussed here would probably be applicable.

III. ENERGY PRODUCTION AS THE STARTING POINT

The policy that we propose begins with energy production and delivery. Energy production is a challenge for remote areas that do not have oil or natural gas. If energy can be produced in remote tropical regions, producing it generates employment, raises output of goods and services, and can provide the means to improve the quality of life. The advantage of producing energy locally depends on the costs and also on the availability of suitable production systems.

In the remote tropical areas selected, energy production, before the typhoon, mostly involved imported gasoline, propane, and diesel fuel. Electricity came from generators that ran on gasoline or diesel, and vehicles used those same fuels. Stoves burned propane or firewood. There was hydroelectric potential, but only small amounts. Draft animals pulled ploughs, carts, or turned windlasses. The energy consumption per capita was low, on the order of 1.5 kWh per day, or 5,000 Btu per day[2]. That compares to the average of 30 to 90 kWh per day consumed in the rich countries[3].

How should remote tropical regions generate electricity and produce liquid fuel, or should they import liquid fuel to supply 100% of their needs including electricity?

There are at least five ways that remote regions can produce electricity: hydroelectric dams, solar panels; windmills; fuel cells; and biomass conversion. We ignore hydroelectric dams in this discussion because if suitable sites exist, it is usually cheapest to take advantage of the potential, and supply part of the region's electricity needs that way. We investigate the remaining four ways, concentrating on biomass conversion. For decades these alternate technologies could not compete with gasoline and diesel. They were

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[2] According to the CIA World Factbook, the average daily electricity consumption per capita in the Philippines was 1.45kWh per day

[3] Calculation based on 2500 kwh per month for residential consumers and 30% of total energy use in residential. The range 30 to 90 kwh is to allow for rich countries that use energy intesively in their manufacturing sectors. If we use kwh as an aggregate metric; we should include propane or firewood for cooking, draft aninls for hauling loads, etc., and convert to kwh equivalent. If we include those other energy sources, the figure might reach 5 kwh per capita per day. Note that the figure 1.5 kwh per day of electricity consumption includes Manila and Cebu City. Excluding those two would lower the average to as little as 1 kwh per capita per day.

more expensive and required frequent attention to devices that local mechanics did not know how to fix. Recent changes in prices of hardware and the cost of oil, however, have made the cost calculations come out differently. In view of the new cost ratios, all four need to be considered.

The price of solar panels has fallen rapidly -- 99% since 1977, and 60% since 2011. The cost of installing a 1 kW system for a U.S. residence has fallen to less than $6000, and the cost of installing a 10 kW system for a larger user is less than $50,000[4]. For the U.S., those capital costs equated to a cost per kilowatt-hour of between $0.19 and $0.29[5]. Operating costs are zero, and maintenance costs are included in the calculation.

Those figures might sound low enough to induce businesses in the two remote tropical regions to switch to solar generation, and keep their gasoline and diesel generators for backup capacity. But the cost of the solar equipment would be higher because of transport costs and markups. Also the rate of discount used in U.S. calculations is too low for remote regions like the two in the Philippines. Capital is scarce in rural tropical regions, and the cost advantage of solar disappears if we use a higher discount rate. So we consider solar a potential competitor as a way of generating electricity, but not yet competitive enough to displace gasoline and diesel generators.

The exception is solar lamps. These compact units use LED lighting, and have a hand crank as a backup for days when the sky is cloudy. These are cheap, costing $20 or less, and will be part of the overall energy mix for regions like the two in the Philippines.

Wind power is the next technology that might be installed as a source of electricity for remote areas like the two discussed here. Commercial-scale wind turbines have achieved very low costs per kWh -- as low as 8 cent per kWh in New England, with reports of 6 kWh for other U.S. regions[6]. These arrestingly low costs, however, are for huge turbines, rising over 150 meters above the ground; and the installations have at least six such huge turbines, and more often have ten. Smaller turbines, rising only 50 meters above the ground, cannot generate electricity as cheaply. And no investor would build a tall structure on islands exposed to the full force of Pacific typhoons.

Fuel cells are the third technology that remote regions might install to generate electricity. These can use propane or diesel fuel as their input, and they are quickly achieving lower cost per kWh generated, so they might be part of the new energy production facilities. We also include hydrogen fuel cells. Those are particularly promising, because hydrogen can be produced via biomass conversion. We discuss this possibility more fully below, as a variant of biomass conversion.

Biomass conversion is the fourth technology to be considered and the one that we examine more thoroughly. To evaluate it properly requires calculating secondary effects. The other technologies considered, namely hydroelectric, solar, wind and fuel cells that operate on propane or diesel all would operate as if the electricity were arriving from a distant source, with minimal local employment and no local production of inputs. The remote regions would obtain electricity by sending money away, either for hardware, spare parts, or fuel. In contrast, biomass conversion would involve local harvesting of green material for the digesters to consume. It would then deliver methane, hydrogen, ethanol, or biodiesel. It would also produce compost fertilizer. The employment and production linkages are important parts of the calculations that we present in this paper.

Biomass conversion, to be properly analyzed, will require an evaluation that includes employment and consumption effects because it would have so many secondary and tertiary effects. It not only would generate local employment, it would also increase local discretionary income. By using local renewable resources to partially substitute for fossil fuels, it saves foreign exchange. The remote region would not have to send its money away to buy so much fuel. The analysis of biomass conversion will also require agronomic analysis, because the feasibility depends on production conditions for biomass, including yield per acre of dry weight, distance to haul the biomass, its composition of woody material, and the average quality of the methane, hydrogen, ethanol, and biodiesel it produces. The analysis will also need to take into account the value of the residue that is left in the digesters after all the fermentable material has been consumed. This residue is fertilizer that can be applied to increase production of export crops or to speed the growth of more biomass.

IV. FROM ENERGY PRODUCTION TO IMPROVEMENTS IN THE QUALITY OF LIFE

For regions where biomass conversion is advantageous, the policy described here will lead to greater availability of electricity and liquid fuel. To estimate the effect on income per capita, we use price elasticity of demand and income elasticity of demand. Using one of these and then the other, it is possible to disaggregate the total response into components, and also possible to distinguish short run response from long run response.

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[4] The cost of installing solar panels has dropped, but it is hard to obtain accurate estimates because subsidies are sometimes included and sometimes excluded.

[5] Several installations in the Southwestern United States have achieved "grid parity" in the sense that their cost of producing a kwh is the same as, or lower than, the cost the local electric utility charges.

[6] For New England there have been announcements of two large wind turbine projects, one on a mountain ridge in New Hampshire and one about 50 miles inland in southern Maine.

As a starting point, before the typhoon assume that electricity cost about US $0.40 per kilowatt-hour. That assumes the diesel fuel or gasoline delivered to either of the two remote regions would cost about US$ 1 per liter. The gasoline or diesel generators would operate at 25% to 35% efficiency, so could operate profitably if electricity can be sold for a price in the $0.40 range[7].

Now assume that the cost of electricity in the remote tropical region declines to $0.20 per kilowatt-hour. The immediate effect for a person consuming 1.5 kWh per day would be to release some of the money the person was spending on electricity. The person would have an increase of $0.30 per day to spend on other things. Note that 1.5*(0.40 - 0.20) = $0.30.

That calculation leads into the next calculation, which is the price elasticity of demand for electricity. In the short run, demand for electricity is inelastic, with a 1% reduction in price leading to an immediate increase in demand of only 0.2%. The reason is that consumption patterns are set, and take time to adjust. Over the longer term a 1% reduction in the price leads to a 0.9% increase in consumption. Applying those elasticities, and assuming they apply for large changes in price, the price effect would mean that there would be a quick increase in consumption from 1.5 kWh per day to 1.8 kWh per day, and over a longer time the increase would be from 1.5 kWh per day to 2.85 kWh per day.

The next calculation is to estimate the multiplier effect of the windfall increase in discretionary income. The population of the remote region would spend less on importing gasoline and diesel fuel. How much local economic activity would this savings generate? The local population of the remote region would range widely in propensity to consume. So to estimate the aggregate increase in demand for goods and services we consider different levels of propensity to consume. At the same time we consider different levels of propensity to consume imports. Imports, in the classical analysis of the multiplier effect, are treated as a leakage of purchasing power outside the region. For purposes of the analysis here, we accept this view of leakage, and that allows us to compute the following table:

V. MULTIPLIER EFFECT OF ECONOMIZING ON IMPORTED FUEL

A single entry in the table is: Marginal propensity to consume 0.9 and marginal propensity to import 0.4 gives

		Propensity to Consume		
		0.7	0.8	0.9
Propensity to Import	0.4	1.4	1.7	2
	0.5	1.3	1.4	1.7
	0.6	1.1	1.3	1.4

Multiplier = 1/(1-(0.9-0.4)) = 1/(1-0.5) = 2.

So the improvement in discretionary income, when the multiplier effect is taken into account, can be between $0.33 and $0.60 per day. That assumes that the per capita consumption of electricity was 1.5 kWh per day, at a cost of $0.40 per kWh, declining to $0.20 per kWh because cheaper technologies for generating electricity are implemented.

For purposes of keeping the scope of this paper narrow, we assume that the improvement is modest and would most likely not be dramatic enough to attract immigrants to the remote regions, but it would deter emigration. Therefore we assume that the population of the two islands does not change in response to the lower cost of electricity.

The next calculation is to estimate the jobs created. These jobs can be classified as direct employment, harvesting the biomass, and indirect jobs, created because of the increase in discretionary income. It is important to note that the jobs to be created are year-round work, not seasonal. In zones with plantation export crops like sugar cane, there is a harvest season, and the rest of the year there is much less demand for labor.

To compute employment effects, and to give information that underpins the cost ranges per kilowatt-hour, it is helpful to give an illustration of a biomass conversion technology, or family of technologies, that is currently being offered by commercial vendors.

VI. BIOMASS CONVERSION TECHNOLOGIES

For remote tropical regions, biomass is abundant and quickly regenerates after being cut and hauled away. Processes to convert it into valuable outputs can be classified according to chemical reactions and steps to produce final outputs. The simplest and most widely applied biomass conversion technology is to produce methane. Biomass digestion to produce biogas conversion is a growing field of interest. Biomass digestion is valuable because it can be used not only to dispose of unwanted wastes (e.g. Maroušek, Zeman, Vaníčková, & Hašková, 2014)to produce energy, but the biproducts from a digestion system can also be valuable in themselves (Maroušek, 2014).

We can estimate the amount of methane obtained from anaerobic digestion of plant matter using the equation from Buswell and Mueller (1952).

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[7] The calculation is as follows: A gallon of No. 2 diesel fuel contains 129,000 btu of energy. There are 3.79 liters per gallon. One kilowatt-hour of electircity is equalivalent to 3,413 btu, so a liter of diesel fuel, converted to electricity at 100% efficiency, is 9.9 kilowatt-hours. Converted at 25% or 35% efficiency, one liter of diesel fuel gives 2.49 to 3.49 kwh. So if a liter of diesel fuel costs $1.00, then the cost per kwh of electricity would be $0.29 to $0.49.

$$C_nH_aO_b + (n-a/4-b/2)H_2O \rightarrow (n/2-a/8+b/4)CO_2 + (n/2+a/8-b/4)CH_4$$

Using the composition of corn silage as a typical plant matter (45% O, 44% C, and 6.3% H by weight) the equation gives a composition of the resulting biogas of 51% methane. Assuming the plant matter is 80% water, one metric ton of plant matter would yield 200kg of dry material, of which 88kg would be carbon. Not all of this carbon would be converted to gas in the anaerobic digester, but 60% of the carbon content could be converted into biogas. This would produce 35kg of methane gas per metric ton of wet material put into the digester, with an energy content of 1809MJ, or 502kWh. This gas can be burned gas in a stove to cook or in a gas-powered refrigerator. Or the methane can be burned to generate steam for a turbine to generate electricity. Our focus is on generating electricity, and in this case, a traditional steam turbine (~35% efficient) would produce approximately 176kWh of electricity from one metric ton of biomass. If used as part of a combined heat and power (CHP) plant, the total efficiency jumps to 85%, with 176kWh of electricity produced, and the remaining energy available as heat for use in other applications.

Another alternative is to use a fuel cell to produce electricity. Fuel cell systems exist that include internal fuel reformers, so they can operate on a hydrogen-rich fuel like methane. These systems are slightly more efficient than electrical turbines (about 40%) so the biogas produced from one ton of biomass would yield 201kWh of electricity from such a system. Similar efficiency gains to those noted above can be achieved in a fuel cell based CHP plant.

A second alternative exists for fuel cells: steam-reform the methane into hydrogen, and then use a fuel cell to convert the hydrogen to electricity.

$$CH_4 + H_2O\ (+heat) \rightarrow CO + 3H_2$$

The carbon monoxide will then react with the steam to produce additional methane:

$$CO + H_2O \rightarrow CO_2 + H_2$$

If we assume the output above of 35kg of methane above, the steam reform process should yield 17.95kg of hydrogen gas, of which 8.98kg came from the methane, and the rest came from the steam. The steam reformation process takes place at high temperatures (~800C) and pressures (3-25 bar), and thus represents an energy input to produce the hydrogen in excess of that contained in the methane. However, the hydrogen produced by such a process, used in a typical (~60% efficient) fuel cell would yield 425kWh of electricity from one metric ton of biomass.

The system that we describe here is offered by at least two commercial vendors. It is discussed here for purposes of illustration, not to recommend any technology or any commercial vendor. It is only one design among many that are available. The system includes a pre-fermentation chamber, where the freshly cut biomass is transformed via hydrolysis, with heat and pressure, to simpler molecules, more accessible to anaerobic conversion. That design delivers higher yields.

The system that we have chosen as an illustration is large. It is intended to be sold to operators of large farms that produce steady quantities of biomass. It includes a pre-fermentation container, where hydrolysis breaks down the polymers in the raw material input (long chains of cellulose) and converts them into monomers. Once they are in that simpler state, the fermentation process can convert more of the available glucose.

Economies of scale are important in any chemical process, so we do not assert that smaller scale systems can produce the same cost per kWh. However, smaller scale systems have the advantage of a lower initial investment.

The system that we describe would use 205 metric tons of biomass per day. That is the output from 1500 hectares of land. By assumption, the land is not being used for crops, and the local inhabitants consider it marginal or useless. The land produces 50 metric tons of vegetation per hectare per year. That is with one harvest per year. More frequent harvests might produce more yield per hectare, but we do not include that possibility. We also assume that laborers are available to cut and transport the biomass to the site where it will be converted.

The system that we describe would produce 425 kWh of electricity per ton (wet weight) of biomass. That would give 31,875,000 kWh per year. That amount of electricity would supply more electricity than the current consumption of the entire population of Guiuan Town and the islands next to it. Two systems of the type we describe would supply more electricity than the current consumption of the entire population of Dinagat Island. If we leave off the steam reformation plant, we can still generate 201kWh of electricity per ton of biomass, or a total of 15,075,000 kWh per year. This would still allow the addition of a hydrogen plant later.

Details of the system, including a diagram of the hydrolysis processing, the hydrogen separation equipment and fuel cell equipment, are in Appendix I. In Appendix 2 we give sensitivity analysis to the estimates of yield and conversion efficiency. Those, in turn, lead to a range of estimates of cost per kWh.

We chose to highlight this technology because the costs of implementing it make it competitive with imported liquid fossil fuels. We now consider the costs of harvesting biomass and transporting it to the processing plant, and arrive at a range that is discussed and computed below.

VII. Direct Employment Effects

All biomass conversion technologies will depend on the cost of cutting and transporting biomass. To arrive at a figure of how much can be paid to workers who cut and transport biomass, we use a method which pays the avoided cost to the local workers.

To begin, we assume that a man can cut about one-third of a hectare per day.

To harvest 1500 hectares would therefore require 4500 man-days. Using 220 working days per year per man, that is approximately 20.5 man-years to cut the biomass. We add 5 more man-years to include transporting the biomass of the processing plant.

What would be the avoided cost of this system? If we assume that this system can produce 31,875,000 kWh per year, and the cost of generating that amount of electricity with small diesel and gasoline generators is \$0.40 per kWh, then the value of the electricity produced would be US\$ 14 million per year. If local users would pay only \$0.20 per kWh for electricity produced by this system, the value of the system would be US\$ 6.375 million per year. Note that 31,875,000 * (0.40 - 0.20) = \$6,375,000.

If we exclude the steam reformation equipment, the annual avoided cost is lower, but so is the cost of hardware and installation. The process without steam reformation would generate 15,075,000 kWh per year. At a cost of \$0.40 per kWh that much electricity would have an annual cost of \$6.03 million per year. If we pay only \$0.20/kWh by using this system, the annual savings would be \$3.015 million per year. After paying the workers according to the terms proposed below, their remaining amount of avoided cost would be \$2.765 million.

If we pay the laborers US\$ 10,000 per year for the arduous work of cutting and transporting vegetation, we use only \$250,000 of the theoretical savings, leaving (in our most complete version of the system to be installed) \$6.125 million to be allocated to other uses. That \$10,000 annual wage is slightly more than double the GDP per capita of the Philippines. Part of the \$6.125 million would be needed to compensate the commercial vendors who produce and install hardware.

The cost per kilowatt-hour for this system would be very low. The only direct cost that we have stated is the wages of the laborers. That would be only about 1.7 U.S. cents per kilowatt-hour. To arrive at a more complete cost figure, it would be necessary to include a cost of the equipment, including installation and maintenance. Some analysts would also include a payment to the owner of the land where the biomass grows, but we do not include that because we assume that the land has no economically important alternate use.

This calculation implies that biomass conversion technologies are potentially very competitive with imported fossil fuels. The yields, conversion factors and efficiency of currently available systems can be much worse than the figures we use here, and biomass conversion still would be very competitive with electricity generated by importing diesel and gasoline. The newer designs make available more of the potential chemical energy in the biomass.

In view of these calculations, it appears that these remote Philippine islands, and similar regions, should consider installing larger-scale alternatives for biomass conversion. They should also consider that smaller scale biomass conversion might be almost as competitive, and much easier to obtain, install, and operate. The land area that we chose 1500 hectares, equivalent to 15 square kilometers, is 1.5% of the land area of Dinagat and 8.6% of the land area of Guiuan.

If more land and labor are available, these islands can produce more electricity, and find new activities that would use the electricity.

VIII. Solar Alternative

Before concluding that biomass conversion is superior to other alternative energy generation technologies for remote tropical areas, we offer data about cost and output of solar panels. The price of solar panels has declined sharply, and the efficiency has also improved. The costs and efficiency are changing rapidly, so we only give a range. Solar has the advantage relative to biomass that, once the panels are installed, they should operate for years with little or no maintenance. Solar is also easily scalable, perhaps more easily than biomass conversion: solar installations can be set up in arrays of different sizes that are the right size for the demand in the immediate area. The arrays can be increased as needed, and the new arrays will be as productive, or more productive, than the ones that were installed earlier.

The data for cost per kilowatt-hour that we have found does not consider economies of scale. This indicates that economies of scale are less important than for chemical processes that use cylindrical or spherical containers to process volumes of material. What does matter is the average latitude because that affects the amount of solar energy that can potentially be collected per unit of area.

The regions and cost ranges are as follows:

United Kingdom	US$ 0.12 - US$0.18
Germany	Euro 0.078 - Euro 0.14
United States	US$ 0.06 - US$ 0.59 (the range includes PV and CSP)
United States	US$ 0.101 - US$ 0.2009

These data indicate that solar panels can compete with gasoline or diesel generators, and can also compete with biomass conversion. The cost advantage of solar has been increasing, especially when tax incentives are taken into account. The cost advantage, especially if recent trends continue, will make solar panels a more widely adopted alternative.

IX. Additional Economic Considerations

To make this brief discussion more complete, we should note that biomass conversion produces compost fertilizer, and some processes also produce high protein animal feed. We have not considered these by-products because the calculations indicate that, even without the by-products, conversion is apparently competitive. We do include the hydrogen gas obtained via the steam reformation process, because it would be converted into electricity. For each total system, it is always necessary to define what are the boundaries of the system. We exclude the fertilizer and animal feed because our focus is on electricity output. Also, the calculations show a cost advantage that is large enough so that valuable by-products do not need to be taken into account.

The economic activity described here would have multiplier effects, in the sense that the workers who cut the biomass would spend their income on the island, and the money would circulate on the island before going away to pay for imports. The multipliers we computed above are in the range of 1.1 to 2.0. That implies that each direct job could create 1 to 2 more, so the total employment effect could be as large as 75 jobs, or if Dinagat Island installs two systems of the sort described, total employment would be increased by as many as 150. There might also be increases in agricultural production and exports, as a result of increased mechanization or application of compost fertilizer. It is tempting to speculate how the additional amounts of cheaper electricity would lead to new activities and higher quality of life.

X. Conclusion

Remote tropical regions can consider a range of technologies to generate electricity. The historical choice of diesel and gasoline generators now has credible challengers, namely biomass and solar generation alternatives. The efficiency of biomass conversion has been boosted by hydrolisis pre-cookers and the price of solar panels has dropped sharply. In addition to cost advantages, biomass conversion creates local employment, and has multiplier effects that are presented here.

The multiplier effects illustrated and computed here are only the classic ones from conventional macroeconomics. It is possible to extend the multiplier effects to include possible future benefits that would arise if the remote regions generate surplus electricity. It is also possible to compute effects on CO2 recapture, but we have truncated at the multiplier effects at the boundaries that are conventional in economic literature.

Despite these constraints on the possible benefits, we obtain results that are clearly competitive with conventional fossil fuel technologies, which justify implementing medium-scale implementation in sites with favorable attributes.

Appendix 1 - Diagram of the Hydrolysis - Hydrogen to Electricity Process

The overall process of producing methane from biomass is diagrammed in figure 1. The anaerobic production of methane relies on methanogentic organisms in the final step. The methanogenetic bacteria, which are the same organisms that exist naturally in ruminant animals, primarily process acetic acid to produce methane (Ostrem, 2004). Depending on the particular biomass input, acidogenetic and acetogenetic bacteria will produce acetic acid for the methanogenetic bacteria to process.

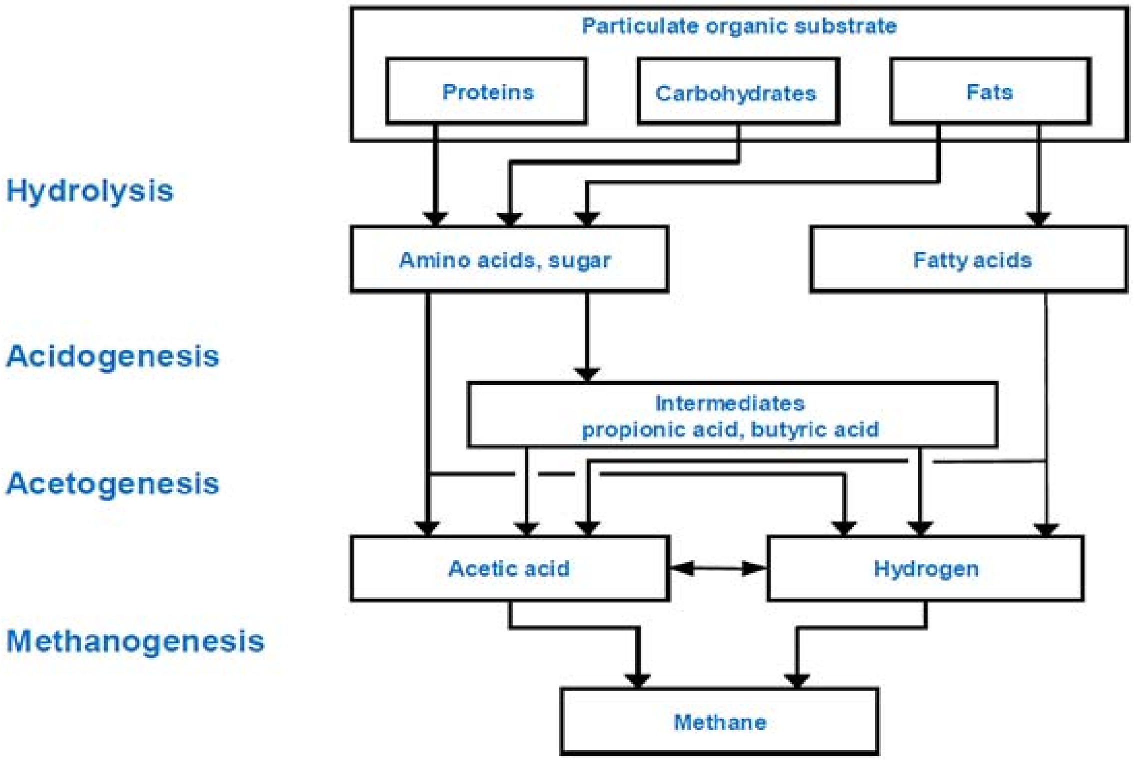

Figure 1 : Anaerobic digestion (Serna, 2009)

The hydrolysis stage is where the complex polymers (eg. Carbohydrates) are broken down into simpler organic monomers (eg. Glucose) which are more readily digested by the bacteria in the later stages. By separating the hydrolysis stage into a separate "pre-digestion" stage, the hydrolysis can be run at higher temperatures and pressures that are more favorable to those reactions occurring rapidly.

It is worth noting that pretreating the vegetative material before it enters the bioreactor can enhance the biogas production from such a system. In the text, we chose corn silage as the analog for vegetation. It has been shown that with corn silage, a hot water maceration process can be used to remove material that will inhibit fermentation and enhance gas production (Maroušek, 2013). Maceration has been shown to be effective with other plant feedstocks as well (Maroušek, 2013b; 2013c) so even though we assumed corn silage was a representative feedstock, such a component would likely be useful in our system.

APPENDIX 2 - SENSITIVITY ANALYSIS

The overall equation for calculating the cost per kilowatt-hour of electricity in this project is:

$$Cost = (22\ workers) \times (\$10{,}000\ \ annualsalary/worker) \times \llbracket (Mass/hectare) \rrbracket ^{\prime}(-1) \times \llbracket (hectares\ used) \rrbracket ^{\prime}(-1) \times \llbracket (Biogas\ methane\ content) \rrbracket ^{\prime}(-1) \times \llbracket ($$

Where the constants are:
88kg carbon per ton (wet) of biomass;
Carbon is 12/16 the mass of a methane atom; and
Methane contains 13.98kWh of energy per kilogram

$$Cost = \frac{Workers \times salary}{M_a \times A \times F_{methane} \times Eff_{digest} \times Eff_{elec} \times F_{Carbon} \times M_{\frac{c}{methane}} \times E_{methane}}$$

Where:
M_a is the annual mass harvested per hectare;
A is the area harvested in hectares;
$F_{methane}$ is the biogas methane content;
Eff_{digest} is the percentage of carbon converted to methane in the anaerobic digestion process;
Eff_{elec} is the efficiency of the electricity conversion;
F_{Carbon} is the fraction (by mass) of carbon in the biomass (treated as a constant, 88kg/wet ton);
$M_{c/methane}$ is the mass fraction of carbon in methane (constant, 12/16);
And $E_{methane}$ is the energy content of methane (constant, 13.98kWh)

In our least favorable case (using the biogas to power an electric generator) the conversion rate is 35%. We consider this as the base case for our sensitivity analysis. We consider varying terms in the denominator as possible variations in the system we propose. In this case, and OAT sensitivity analysis is straightforward: the reduction of any term by a factor of *x* causes a resulting increase in the cost by the same factor *x*. In the table below, we consider cases in which all our estimated factors are too favorable.

	Annual Mass per Hectare (tons)	Hectares in production	Biogasmeth anecontent (%)	anaerobicconv ersionefficiency (%)	electricconver sionefficiency (%)	Final cost ($/kwh)
Nominal assumptions	50	1500	51	60	35	0.00190
Each factor 10% less favorable	45	1350	45.9	54	31.5	0.00321
Each factor 20% less favorable	40	1200	40.8	48	28	0.00579

We also consider the possibility that we have underestimated the labor required to keep the system operating:

5 additional workers						
	Annual Mass per Hectare (tons)	Hectares in production	Biogas methane content (%)	anaerobic conversion efficiency (%)	electric conversion efficiency (%)	Final cost ($/kwh)
Nominal assumptions	50	1500	51	60	35	0.00228
Each factor 10% less favorable	45	1350	45.9	54	31.5	0.00386
Each factor 20% less favorable	40	1200	40.8	48	28	0.00695
10 additional workers						
	Annual Mass per Hectare (tons)	Hectares in production	Biogas methane content (%)	anaerobic conversion efficiency (%)	electric conversion efficiency (%)	Final cost ($/kwh)
Nominal assumptions	50	1500	51	60	35	0.00266
Each factor 10% less favorable	45	1350	45.9	54	31.5	0.00450
Each factor 20% less favorable	40	1200	40.8	48	28	0.00811

Note that in the worst-case scenario, that we have underestimated the required labor by ten workers, and that our assumptions about biomass conversion are 20% high across the board, the cost is $0.00811/kWh. If the electricity such a system produces could be sold for $0.2/kWh, that would still leave over half of the electricity revenue available.

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