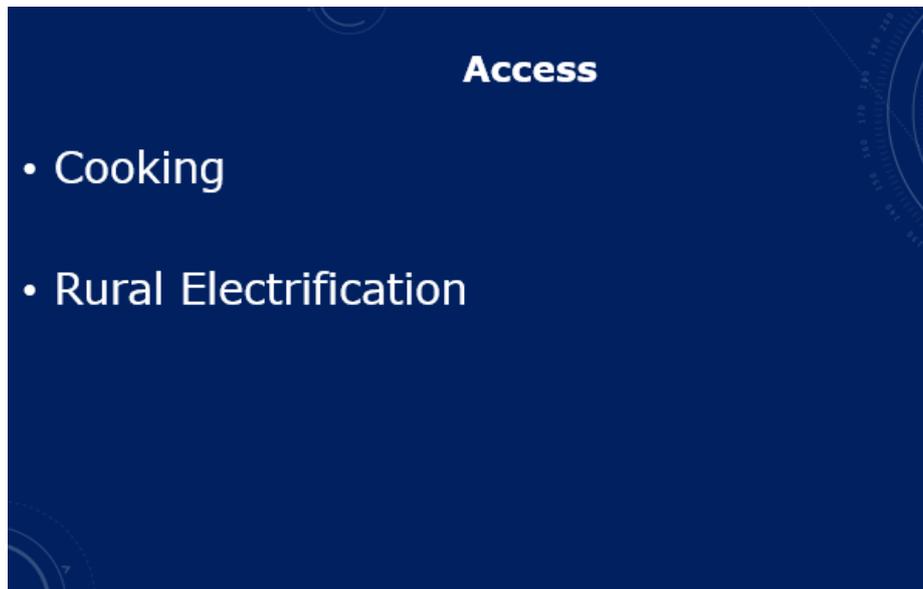


Energy Resources, Economics and Environment
Professor Rangan Banerjee
Department of Energy Science and Engineering
Indian Institute of Technology Bombay
Lecture 24
Energy Policy examples – Part 1

In the previous module we have seen what is meant by an energy policy, we have also seen a framework to analyse energy policies. And we looked at the air quality in Delhi and the INDC India's commitment in Paris and try to analyse how we can analyse these policies and how they are being implemented. We are continuing with this and we would like to like take a look at some examples of energy policies.

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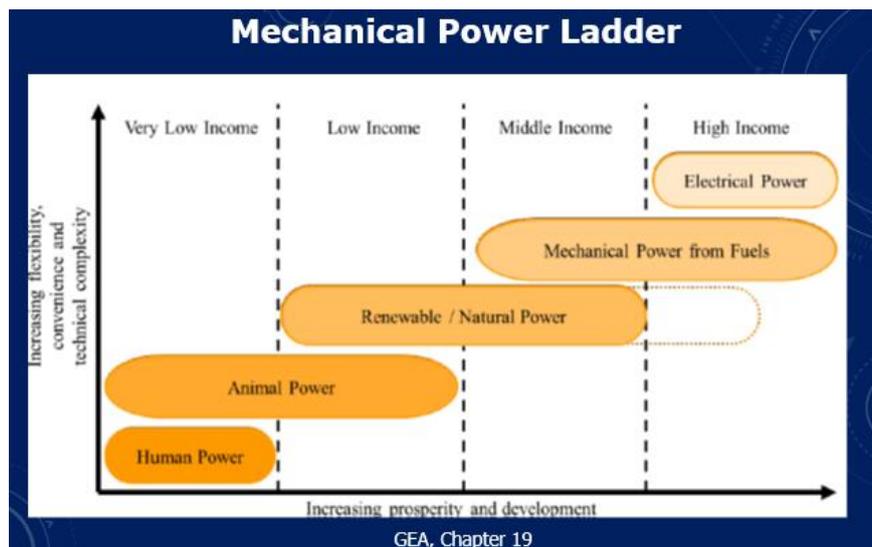


Let us look at access and as you know, for every country, especially for developing countries, the issue of access is one of the important energy goals. And that means we would like to provide affordable access to clean energy to the entire population. And in terms of this in the Indian context, we want to have clean cooking fuels.

The predominantly the largest chunk of our population still uses solid fuels, biomass agricultural residues, typically in chulas with very low efficiencies and with adverse environmental impacts in terms of local indoor air pollution, which causes an impact in terms of respiratory diseases.

So the idea is, can we switch from these solid fuels to more convenient fuels, like LPG, electricity, can we convert them to modern biofuels? Can we look at solar cooking and then the question of electrification and we have had very significant progress in terms of connecting almost the entire, the entire country is now connected to electricity, but several households do not have connection because of whole host of issues related to income affordability, so rural electrification is another issue.

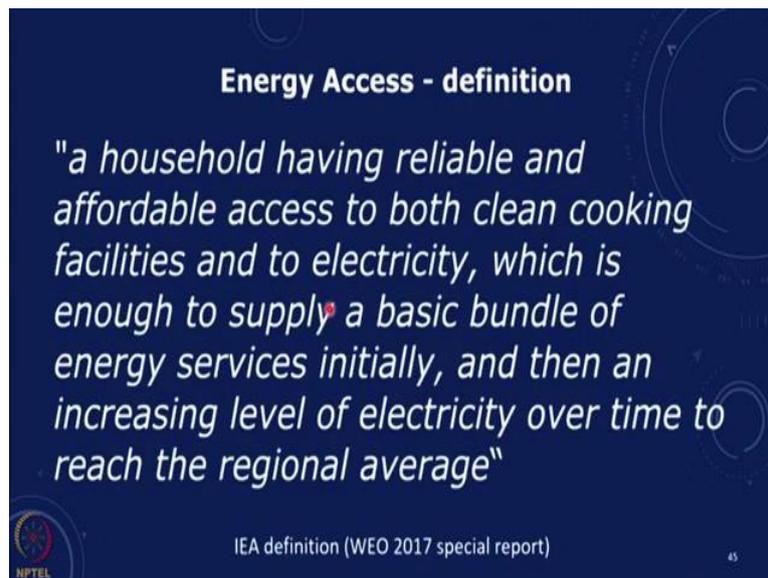
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So, when you look at this, we can see that you know, with increasing prosperity, the process of progress is where we started with initially just using human power, then going to animal power and then initially going to renewable and natural power with wind and water. And then we created basically everything started going into the fossil fuel where you can transfer and you had the centralized grid.

And you had fuels, coal, oil, natural gas and going towards electricity. So, even when we think in terms of cooking also we start there is this energy ladder, where we go from solid fuels to gaseous fuels and electricity. And with income, one actually moves towards using more convenient and cleaner fuels.

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What is the definition of energy access? Energy access is a household having reliable and affordable access to both clean cooking facilities and to electricity, which is enough to supply a basic bundle of energy services initially, and the idea is that this basic bundle or the level should keep increasing and then an increasing level of electricity over time to reach the regional average.

That means the idea is this is the definition by IEA part of the World Energy Outlook 2017 special report on access, the idea is that everyone should have access to clean cooking and electricity and to meet their basic needs and over time, they should keep increasing to go towards the regional average local or regional average.

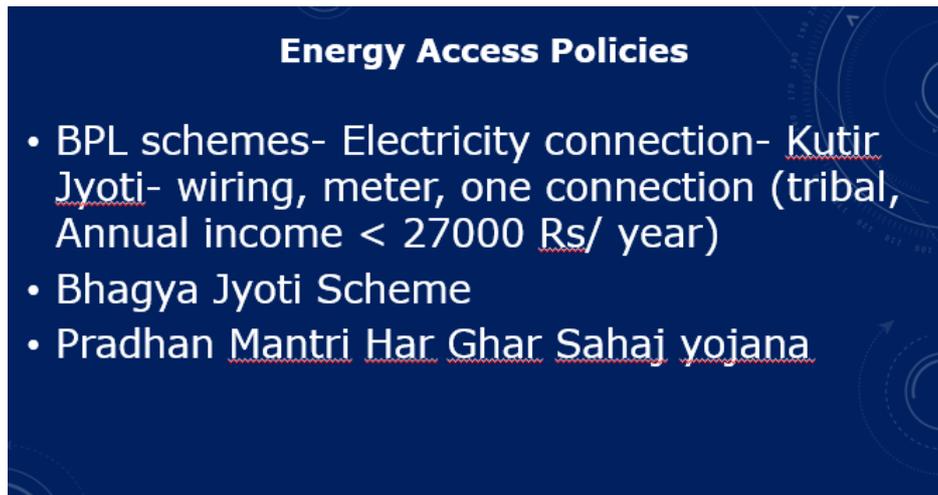
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Nation	Energy Carrier	RQ1	RQ2	RQ3	RQ4	RQ5	UQ1	UQ2	UQ3	UQ4	UQ5
		%	%	%	%	%	%	%	%	%	%
Indonesia	Electricity	64	73	79	82	88	93	96	98	99	99
	Kerosene	90	91	91	93	93	93	94	93	86	62
	LPG	1	1	1	2	8	1	5	12	24	48
India	Electricity	31	44	53	63	79	75	90	94	97	98
	Kerosene	97	96	94	90	79	85	72	55	41	21
	LPG	1	2	6	12	38	19	46	68	83	90
Brazil	Electricity	50	57	63	69	78	84	91	93	95	96
	Kerosene	21	15	12	9	5	2	1	1	0	0
	LPG	42	61	75	85	90	91	98	98	96	85
Ghana	Electricity	2	5	7	9	19	28	27	34	43	61
	Kerosene	29	27	25	27	27	13	10	6	6	4
	LPG	0	0	0	0	2	0	2	4	8	10

And if you look at this, over the different income classes, when we look at, you know, the quintiles, quintiles means divide 100 into 5, 20 percentiles that means lowest 20 %, the next and then and so on. So, we can do that in terms of rural and urban, you can see basically the difference in terms of this, where you will find that in the context of electricity, the lowest quintile has a smaller percentage where they are using electricity as the higher income, this goes to about 79 % in the urban it is almost like 100 % and so on.

So, the fuel mix is very dependent on the income and the lower income households are using biomass, traditional biomass and maybe kerosene for the lighting.

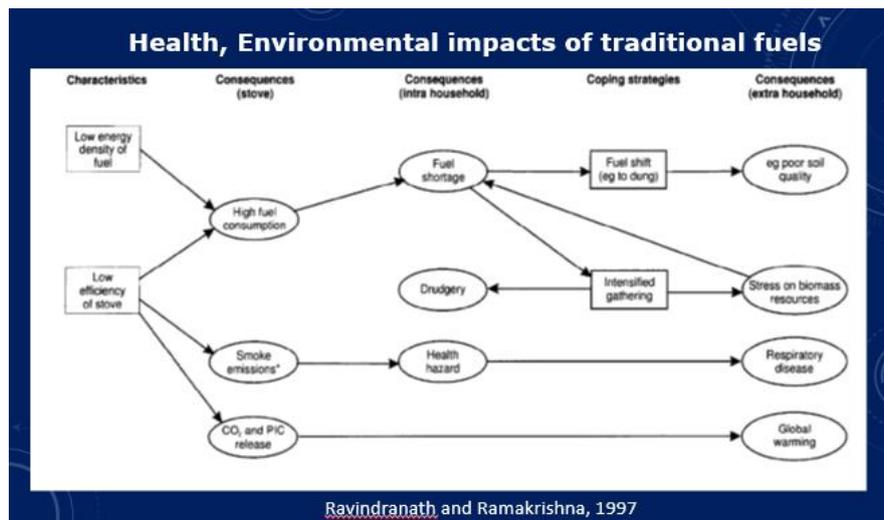
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And so, there have been a number of different policies and schemes. So, in India at the, for households which are below the poverty line, an electricity connection is in many states provided free of cost. And this is being given for particular in many cases there is a Bhagya Jyoti and the Kutir Jyoti scheme.

Wiring, meter, one connection, there is a limit in terms of the connected load to be provided, but this is almost given sort of free of costs and even the connection costs. So Bhagya Jyoti scheme and now there is the Pradhan Mantri Har Ghar Sahaj Yojana, in many of these cases there is an incentive for the initial upfront connection cost and then there is a subsidized electricity use. However, still the uptake of these some of these there are issues related to that.

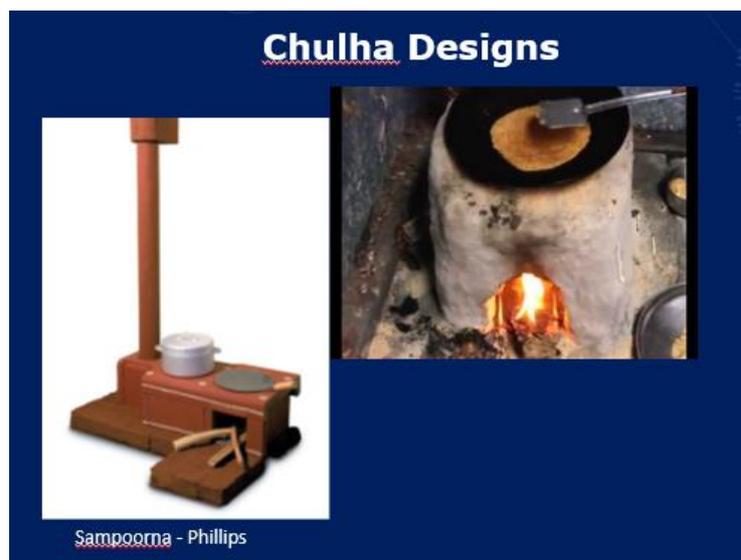
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We can look at now, if you look at the cooking, you can see this is from a paper by Rabindranath and Ram Krishna, where you see what happen, what is the implication of looking at different kinds of efficiency, low efficiency of the stock and the emissions, the health hazard, respiratory diseases, it also results in global warming.

And there is a also can have more time taken for collection and there is a stress on the biomass resource. There is a drudgery and then also can result in poor soil quality, there are there are many different kinds of impacts.

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There different kinds of chulha designs and it is possible. So, this is a conventional kind of chulha, if you see using solid fuel, there have been improved through the designs which can be smokeless, which can improve the efficiency and some of these designs are also available in

the public domain where anyone can actually manufacture them, there the initial capital cost is slightly is higher. But then there is an advantage in terms of the efficiency and the health impact.

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And of course, as we go up this stream, we are looking at kerosene and LPG with much higher rate at which we are providing the energy or the power, the efficiencies are high and there is much better controllability in terms of turning up and turn down. This is a sort of kerosene pressurized kerosene stove and this is an air fire electric air fire.

So, and many of these, in terms of convenience, in terms of efficiency, in terms of emissions, they are much better.

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Chulha Costing (Sample-2011)

Costing for Saral Chulha fabrication and installation as on 23 October 2011
Prepared by Junglescapes Charitable Trust, Lakkere, Karnataka, India

Cost Item	Quantity	Rate	Amount per chulha
1 Cement - Basic Quality (kgs)	22	6.2	136
2 Stone grit 6 mm (Bandis)	2	25	50
3 Stone powder (Bandis)	1	10	10
4 Chicken mesh (3 ft by 1-1/4 ft)	1	40	40
5 Steel bars (4-6mm)	in kgs		50
2 feet bars (nos)	2		
10 inch bars (nos)	7		
6 Wastage on above raw materials at 5%			14
7 Red cement paint for finishing			10
8 Chimney Pipe (3 inch)	1	100	100
9 Chimney Cap (3 inch)	1	40	40
10 Clamp for chimney pipe	1	10	10
11 Grate	1	180	180
12 Raw material transportation (batch of 10)			50
13 Labour for fabrication and finishing (4 hours)			75
14 Transportation of chulha to installation site (batch of 6)			50
15 Bricks for installation (nos)	15	5	75
16 Labour for installation (3 hours)			50
17 Profit margin for entrepreneur			75
Total cost			1016
18 Add: Mould amortisation			80
Total cost including mould amortisation			1096
Rounded off			1100

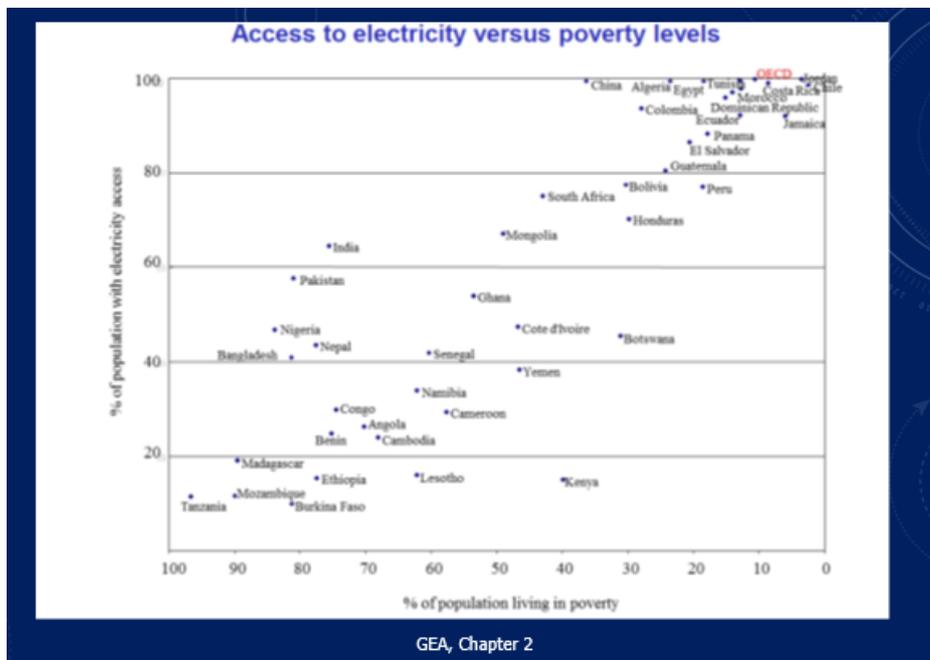
Notes

- All rates are based on current market prices of raw materials at Gundlupet
- Landed cost of mould of Rs 24000 assumed to be amortised over 300 chulhas (life as indicated by Fomo)
- These rates are based on wholesale market prices of raw materials under ideal conditions. The prices in the retail hardware stores (or when there is a shortage) can be higher by 5-10% than what is indicated above.

http://www.lowsmokechulha.com/index.php?title=File:Chulha_costing_2011.ppt

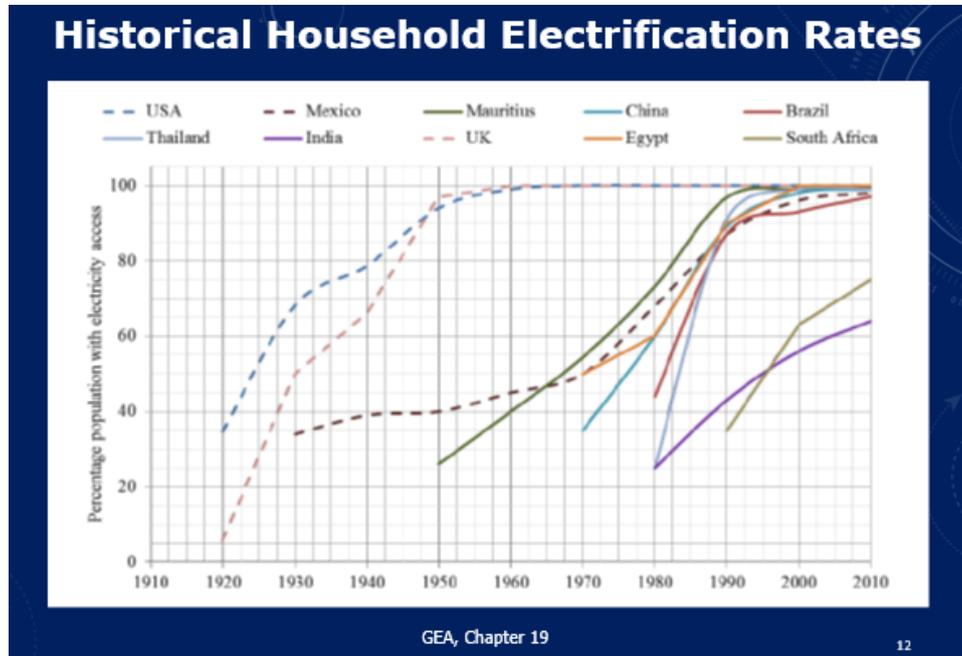
Some of these chulhas which have been developed have been the estimate for this looks low smoke Chulha of the costs have been there. And you can see that we are talking in terms of a couple of thousand rupees and one can think in terms of how to cost this.

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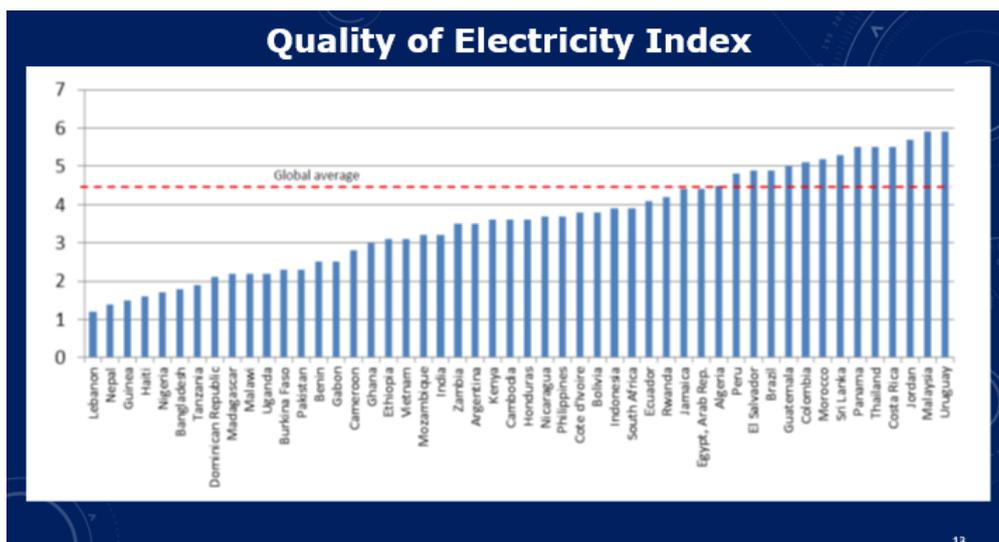
In general the access of electricity is linked very clearly with poverty. And this is from the global energy assessment. You can see many of the Latin American and African countries with high poverty levels also have less electricity access.

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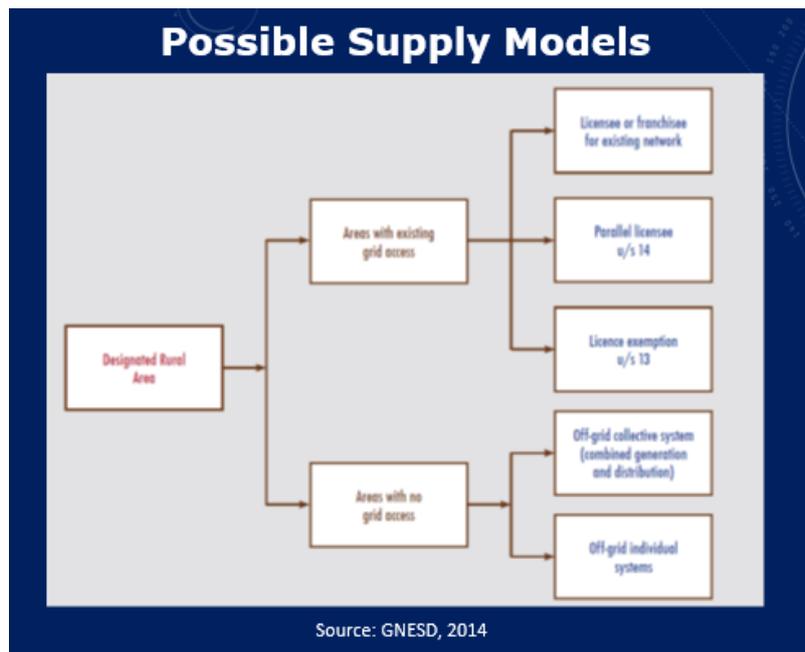
We have been relatively low pick up, but now we are going towards nearing at least 100 % in terms of the village connections and slowly going towards 70-80 % in terms of households.

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The other issue which is there is that in many of these cases you will find that the quality of electricity in terms of number of hours of shortages and the reliability is another index that we can see.

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There are apart from the centralized grid, there are options where we can have essentially different kinds of micro grids and we can create a license or a licensee or a franchisee, we can have a parallel license, we can have an off grid collective and there are different kinds of building business models for this.

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Capital Subsidy

Scheme	Time frame	Target under the scheme	Ownership	Finance	
				Subsidy vehicle	Central Financial Assistance
RVEP	2001 onwards	Electrification of census villages and hamlets near electrified villages that are not likely to receive grid connectivity	VEC/Community	Capital Subsidy subject to upper limits	90% of the costs of various renewable energy devices/systems subject to pre-specified maximum subsidy <i>Maximum CFA per household is US\$300*</i>
VESP	2004-09	1,000 villages to be electrified within the current 5-year plan	VEC/Community	Capital subsidy Operational subsidy for first 2 years	90% of the total project cost <i>Maximum CFA per household is US\$333</i> 10% of the total project cost
DDG under RGGVY	2009 onwards	N/A	State Government	Capital subsidy Operational subsidy for 5 years	90% of the total project cost 10% of the total project cost
JNNSM (Off-grid component)	2010 -2022	20 million decentralised solar PV systems	Local bodies/State Government/	Capital subsidy	US\$1.5/W _p (with battery storage) US\$1.17/W _p (without battery storage)

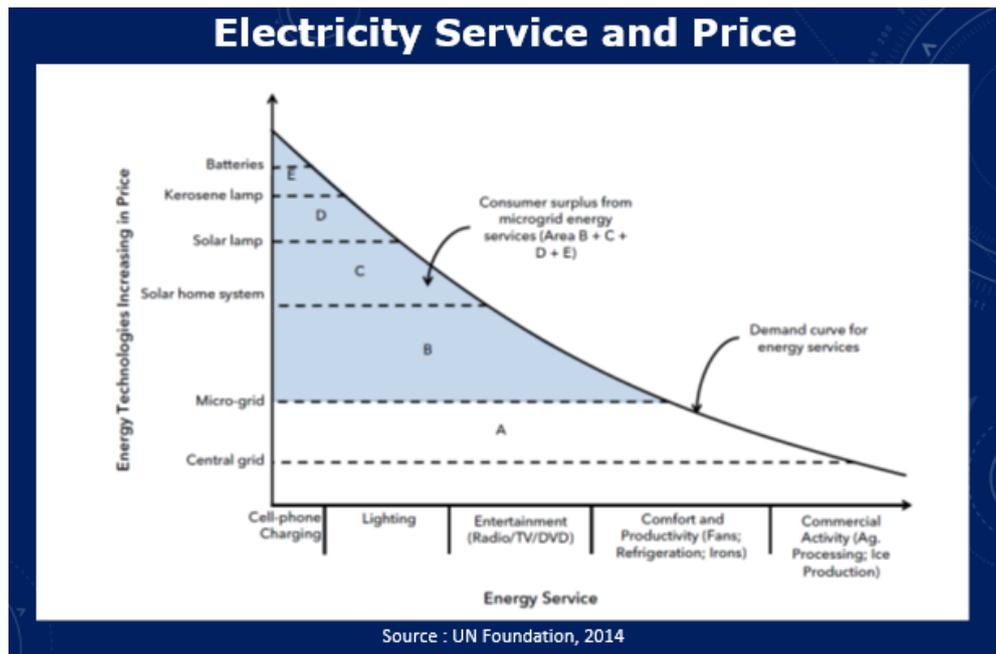
Source: GNESD, 2014

We have had in under these programs, the rural village electrification program, village energy security program, the recently DDG, which was earlier the RGGVY and we have essentially

provided capital subsidy for many of these villages which are remote. And some of these actually provide almost 90 % of the total project costs as a subsidy.

The difficulty, of course, is that you have to have a mechanism so that subsequent maintenance, if you have a PV battery system, the battery payment, and so on can be created. Again, there is even the national solar mission also there is an off grid component where we can look at this.

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You would be surprised to note that for low usage electricity, some of the remote rural areas for a mobile charging, they pay a significant amount. It is a small amount of electricity that is required. But if you come converted into per kilowatt hour, you will find that people actually end up paying quite a significant amount are willing to pay but it is it is for a small amount of electricity.

As we go up, go down, increase the number of energy services, the first important one is cell phone charging, then comes lighting, then comes entertainment in terms of TV and cable TV, and then comes the other things in terms of comfort, fans and refrigerators and so on and so you can create this kind of a service and demand graph.

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Tariff Comparison

Developer (Business Model)	Tariff Price (Local Currency)	Tariff Price (USD, January 2014 exchange rate)	Operating Expenses	Major Maintenance	Capital Costs ²	Profit (for Developer)
CREDA (FS)	5-10 Rs/mo.	0.08 - 0.16/mo.	Partial	No	No	No
DESI Power (PS)	5 - 8 Rs/kWh	0.08 - 0.13/kWh	Yes	Yes	Partial	No
Green Empowerment/ Tonibung/PACOS (PS)	3 - 20 Ringgit/mo.	0.91 - 6.09/mo.	Yes	Partial	No	No
Haiti (PS)	~200 HTG/mo.	4.55/mo.	Yes	No	No	No
Husk Power Systems (FP)	~150 Rs/mo. (average)	2.41/mo.	Yes	Yes	Yes	Yes
OREDA (FS)	10 - 30 Rs/mo.	0.16 - 0.48/mo.	Partial	No	No	No
WBREDA (PS)	80 - 270 Rs/mo.	1.28 - 4.32/mo.	Yes	Partial	No	No

Source : UN Foundation, 2014

And there are different models and we have had a large number of distributed generating models, some of them are not for profit, some of them are for profits. And there are different kinds of prices and mechanisms and if you are interested, you can look at this in more detail. I am not going to cover this.

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Community Involvement

Categories (of Voluntary/ Paid Village Participation)	DESI Power	GE/T/P	EDH	HPS (BM Model)	OREDA	CREDA	WBREDA
Daily Operations	✓	✓	✓	✓	✓	✓	✓
Major Maintenance					✓	✓	✓
Collect Tariffs	✓	✓	✓	✓	✓	✓	
Enforce Penalties			✓				✓
Initiation/ Planning Strategy Help		✓		✓		✓	✓
Construction Labor		✓				✓	
Village Energy Committee Existence	✓	✓	✓		✓	✓	✓
VEC Bank Account Existence		✓	✓		✓	✓	
Contribute Land	✓	✓		✓	✓	✓	✓
Initial Community Ownership		✓					
Community Eventually Owns					✓		

Source : UN Foundation, 2014

In this and in many of these cases what happens is what happens is that there is local involvement in terms of operation and maintenance. For instance, in the Sunderbans, there was

a the collective of the village energy and the village community and they would actually train people. There was also load limiters so that in case the load went beyond a certain point, and if that happened a number of times, they would the household would be cut off, there was a fixed rate.

In some cases there are fixed rates in some cases they are metered. There also we are thinking in terms of prepaid metering and so, there are a number of different kinds of things.

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Developer	Efficient Appliances	Limiting Business Hours	Restricting Residential Use			
			Customer Agreements	Home-Wiring Restrictions	Over-Use Penalties	Load Limiters
CREDA	✓		✓	✓		✓
DESI				✓	✓	✓
GE/T/P			✓		✓	✓
Haiti						
HPS	✓		✓	✓	✓	✓
OREDA	✓		✓	✓		✓
WBREDA	✓		✓	✓	✓	✓

Source : UN Foundation, 2014

And as you can see in terms of the measures, which are the many of these have been encouraging demand side management or energy efficient operations equipment, because if we use energy efficient equipment, then the requirement for the PV or the modules, the rating decreases and in this becomes overall much more cost effective.

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Affordable Access

The top slide features a map of Maharashtra with district boundaries. Three red dots indicate the locations of Rajmachi, Dissoli, and Lonarwadi. An inset map of India shows Maharashtra highlighted in purple. The title 'Affordable Access' is at the top.

The bottom slide contains a block diagram of a solar power system and two photographs. The diagram shows the following components and their connections:

- Solar Array 5X1 kWp
- Charge Controller 40 A, 120 V
- Battery 800 Ah
- Inverter 7.5 kVA
- AC load 2.5 kW

Arrows indicate the flow of power: Solar Array to Charge Controller, Charge Controller to Battery, Battery to Inverter, and Inverter to AC load.

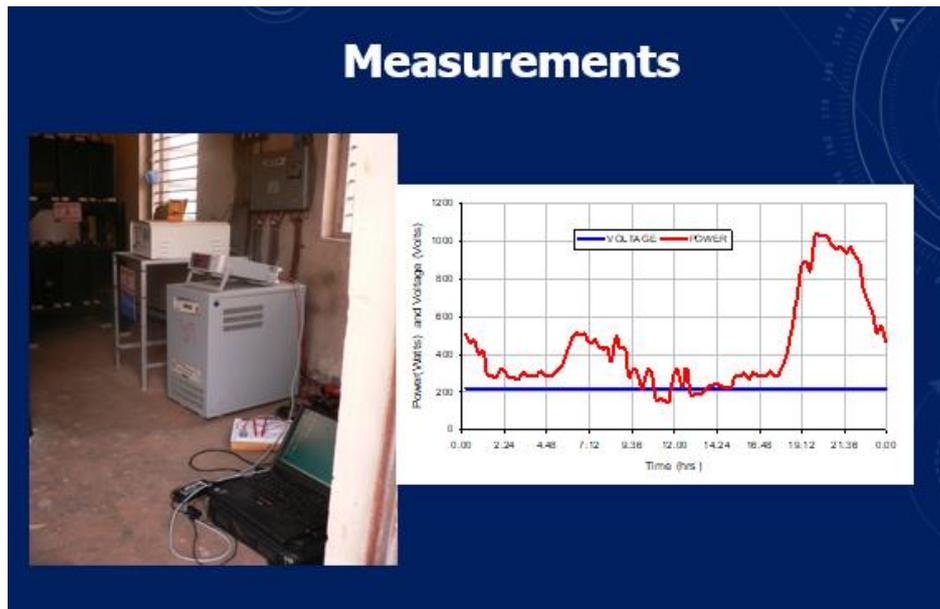
The left photograph shows a 5 kWp solar PV power plant at Rajmachi Village, Maharashtra, with several solar panels mounted on a structure. The right photograph is an aerial view of the village with a red circle highlighting the solar installation area.

No. of house holds: 29
Connected load : 1.4 kW

5 kWp Solar PV power plant at Rajmachi Village, Maharashtra

So, just to give you some idea, this is for affordable access, this is a small village in Maharashtra, there is a solar array charge controller battery and AC load.

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And if you look at it, you can see that the most of the load is basically in the evening and with the result that the capacity factor would be low and this would result in high average prices.

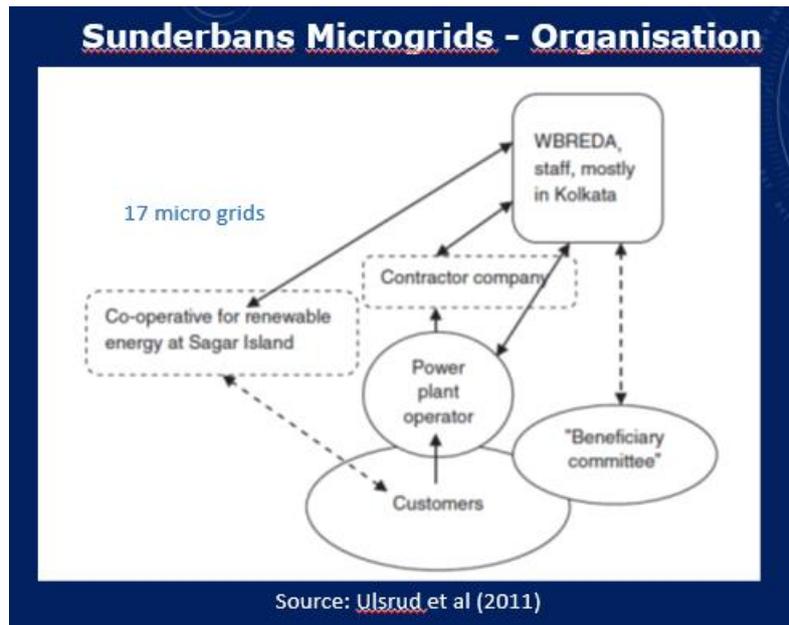
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Integrated design-Summary

Name of the plant	Connected Load (kW)	Plant Capacity		Distribution loss (%)		Plant capacity factor (%)		Energy cost Rs / kWh	
		Existing	Designed	Existing	Designed	Existing	Designed	Existing	Designed
Solar PV, Rajmachi	1.4	5 kWp	4 kWp	4.6	0.5	8.3	11.5	32	25
Biomass gasifier, Dissoli	6.9	10 kW	10 kW	12.3	2.0	8.8	12	29-37	21-25
Biomass gasifier, Lonarwadi	10.7	20 kW	10 kW	14.6	2.7	5.6	14	43-54	16-25

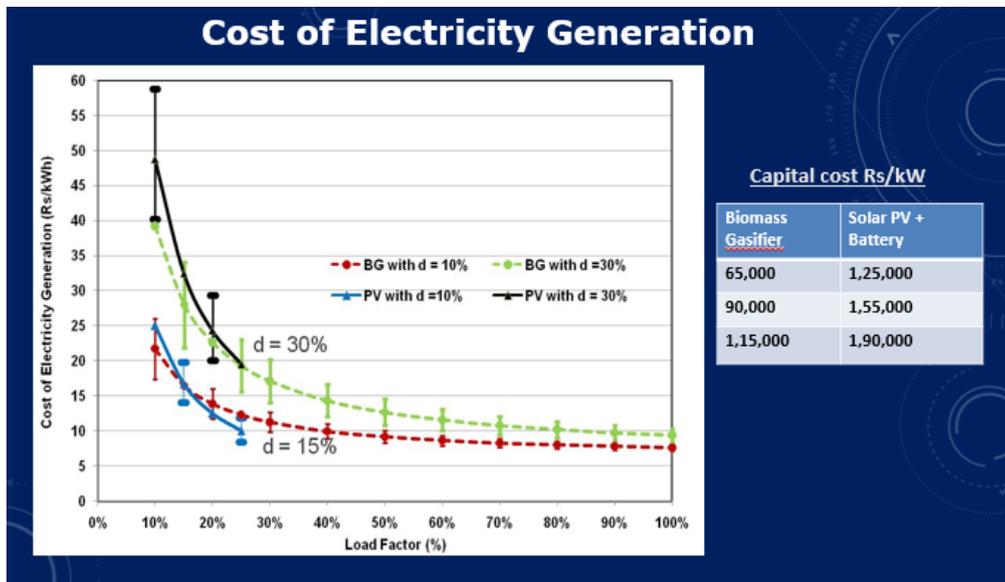
So, it is quite common when you look at some of these, this is these are three biomass gasifier and PV, the energy costs are of the order of 30 to 40 Rs/kWh. Of course, we have worked out that if this is the design efficiently, they could be lower they are often oversized, and then that is because the demand estimation is accurate.

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And then, I talked to you about the Sundarbans model where there is a cooperative for the renewable energy at different kinds of in the Sagar Island, there are 17 micro grids, there is a West Bengal Renewable Energy Development Agency, there is a power plant operator their customers and there is a committee of the beneficiaries and this is how it sort of work.

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You can of course, see it when we look at costs of energy, if the load factors are low, the costs are going to be high and so on. So whenever we talk about these micro grids or isolated grids if they are linked with only residential load, load factors are going to be low. The way to do

this is to add some industry or add some base load or to add telecom towers so that capacity factors increase and the average the costs of generation.

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Selco Case study

- For profit company – Solar Home systems – started 1996 – sold about 100,000 SHS
- 90% of products – credit schemes
- Partnership with 9 banks – interest rates between 12-17%
- Financing Institutions pay 85% of the amount- monthly payments of Rs 300- 400 over a period of 5 years
- Financing/ repayment options – tailormade to end users – paddy farmers – repayment schedule based on crop cycle, street vendors – daily payments – Rs 10
- Funding from REEP – meet margin amount for poor customers, reduce interest rate



Source: SELCO, 2011

We talked in during the financing I talked to you about the Selco example where they have providing innovations in financing so that they can look at solar home systems.

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DESI Power

- Biomass based power solutions – Bihar- 25 kW to 100 kW
- Local distributors – decide pricing
- Registered under CDM and sold CERs to Swiss buyer
- MNRE funds, Promoters Equity, ICICI Loan
- Monthly rate based on no of bulbs / loads, Circuit breaker to limit consumption
- Irrigation pump users Rs 50/ hour, Household Rs 120- 150 per month
- Underground trunk wiring-distribution
- Enabling micro-enterprises –battery charging station, flour mill, workshop etc
- Tie up with Telecom towers – increasing capacity factor

The another company which has been doing this is the DESI power which has been aggregating different kinds of biomass base powers solutions in Bihar and putting this in terms of the total amount of CO₂ savings and so, getting the credit in terms of the certified emission reduction and then getting it registered under the clean development mechanism, they have also tied up with the telecom towers.

The problem in many of these cases is that, when the grid has come to these locations, at some points these they have not been able to compete. So, they have also looked at fixed costs in terms of irrigation pumps and households.

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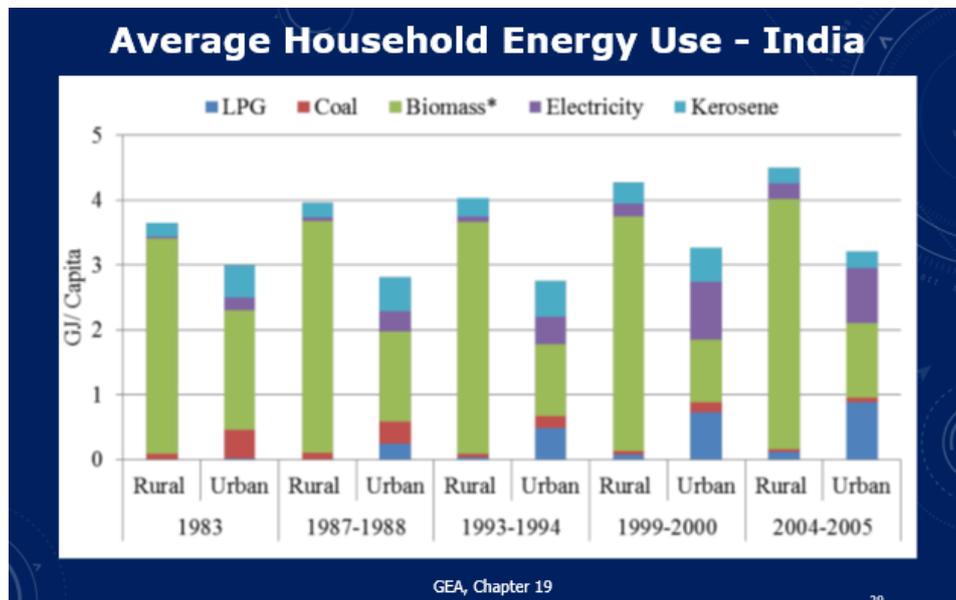
Husk Power

- Initial funding – prize money
- 30-100 kW – biomass gasifiers- based on rice husk
- Energy audit of households
- Focus on household demand for lighting
- Lower production, operating costs – use of bamboo, asbestos
- Overhead pole wiring
- Directly reach end user

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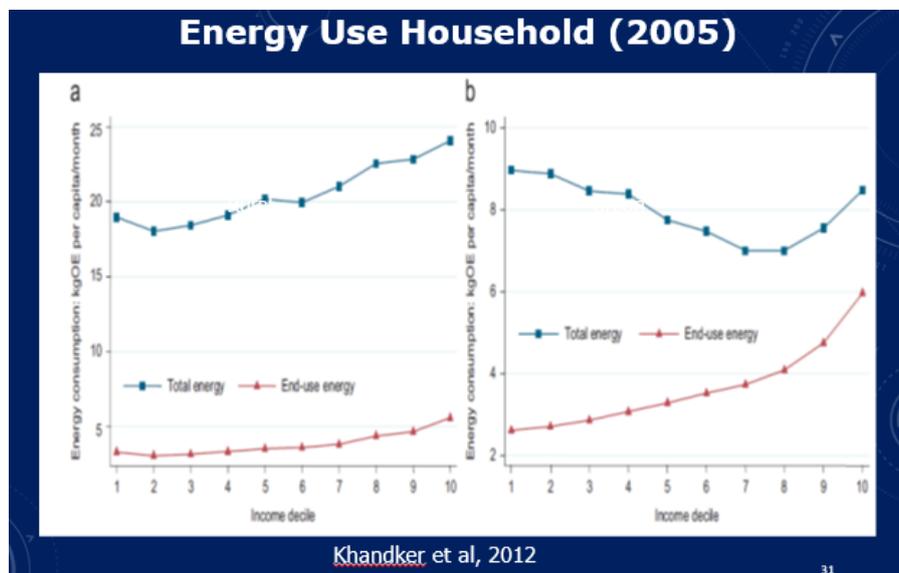
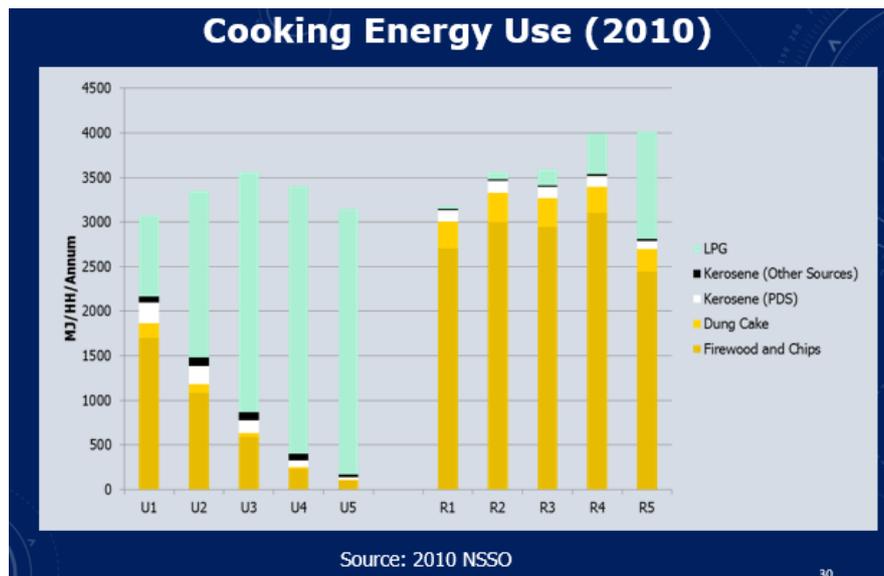
And husk power on a similar again biomass base power, but they initially started with their own prize money and they looked at overhead pole wiring, they directly reached the end user.

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And if you see in terms of the usage of for cooking, you look at rural and urban households over time and you can see that the mix of different kinds of fuels has changed over a period of time.

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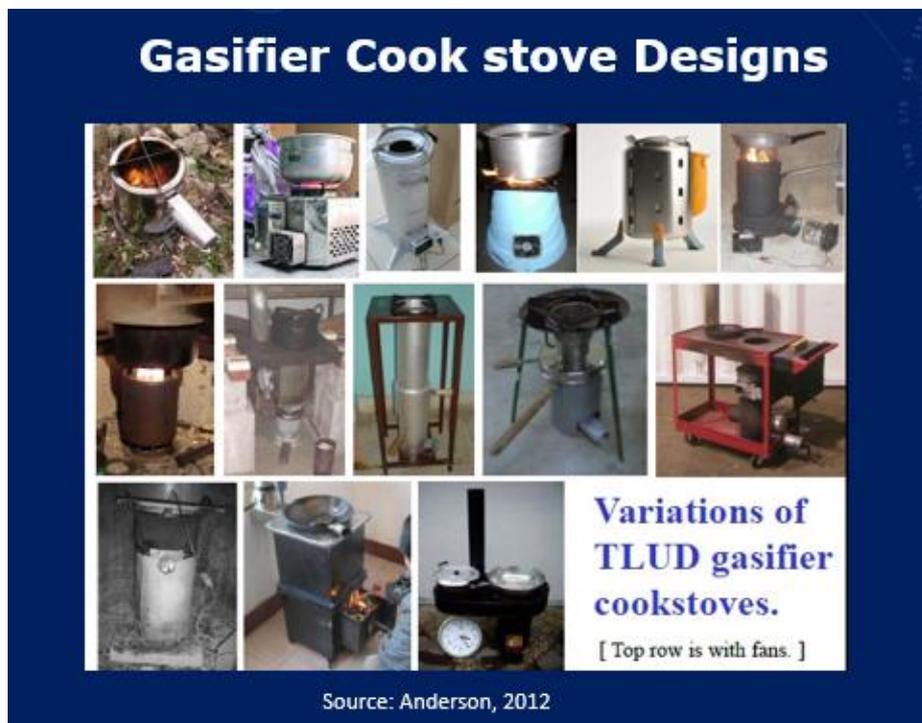
You can look at this from the NSSO data which is collected every few years National Sample Survey, and where you can see, for the income deciles this is plotted the energy consumption, the end use energy and the total energy. And the interesting thing that you will find is that the end user energy in the case of urban the total energy actually initially declines and then increases.

And this decline is because then with the, in the lower income classes, you are using more traditional fuels and because of that, though the end use energy is keeping on increasing and because of the poor efficiencies, you can see this kind of mix, this is from paper in 2012.

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Comparison Cooking fuels

Fuel	Avg Price/Useful Energy	Heat Rate (MJ/Std. Unit)	Thermal Efficiency %	Emission Factor PM (gm/kg)
Fuelwood	0.777	16	15	3.2
Dungcake	1.379	15	15	3
Kerosene PDS	2.557	35	35	1.54
Kerosene Other	5.773	35	35	1.54
LPG	0.871	45	60	0.32



One can then make a comparison in terms of calculations. Now, it is possible to have modern biomass based energy systems which will give you actually biomass gasifier based systems which give you LPG quality fuel and LPG and control.

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So, for instance, if you look at this flame, this is a rice, this is based on the gasifier, but it is firing rice husk and you can see that this flame is just like LPG flame, so this is another thing which can be done.

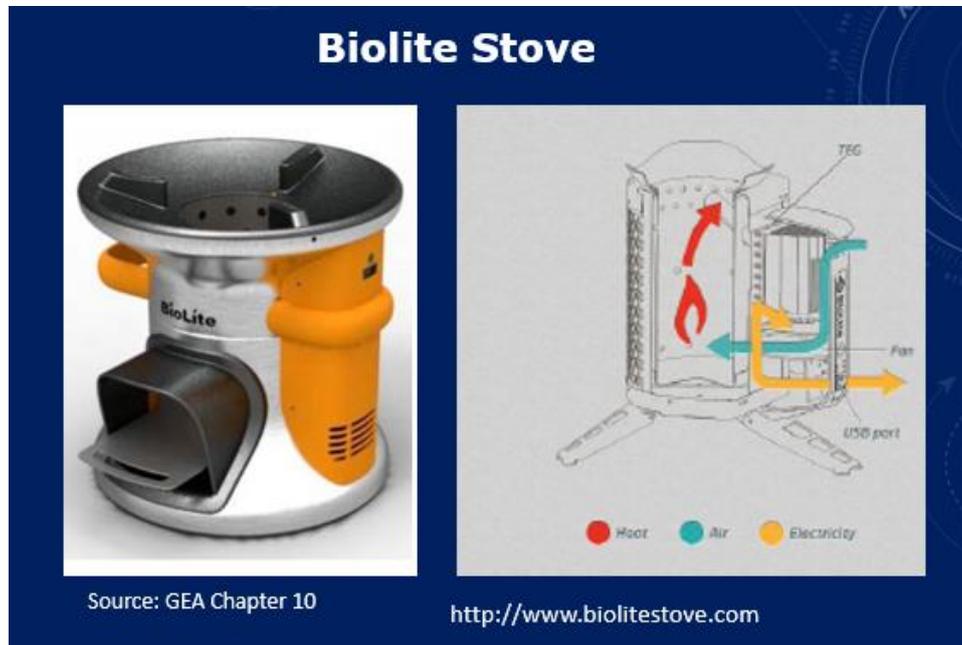
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There are the stove designs and this is done by the research group at ISC Bangalore, this is the Oorja stove which needs pellets like this. Now, what happens here is that this becomes more efficient, it improves the, reduces the emissions, better from a health impact, but then the feedstock earlier biomass was just being collected and there was no price.

Now this we have marketize and we are now creating this as a market where they will have to buy these pellets and we need to have this chain, so there is a cost implication of this.

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This is an innovation from the US, it is a biolite stove. And the interesting thing about this stove is there is a thermoelectric generator. We using the exhausts of the bio of the stove, and this is used to generate electricity, can run a small fan which caused the induced draft and it can also charge can be connected to get an LED light or you can charge your cell phone. So, this is an interesting kind of innovation of course, this will cost more than the normal stuffs.

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Compact Biomass Gasifier



Source: www.arti-india.org/

1 m³ – digester – 2 kg kitchen waste

0.5 m³ – digester – 1 kg kitchen waste

There are different kinds of biomass based stuffs made by some of the technical NGOs in Pune. and Compact Biomass Gasifier you can see.

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Subsidy Mechanism

Government Intervention	Example	Lowers cost of production	Raises cost of producer	Lowers price to consumer
Direct financial transfer	Grants to producers /service providers Subsidy for bulk power supply Direct operating subsidy Capital subsidy	✓		
	Grants to consumers Direct connection subsidy Connection subsidy through service provider Direct consumption subsidy to low power users (lifeline rate)			✓
	Low-interest or preferential loans: Financing subsidy for producers Consumer credit for new connections	✓		
Preferential tax treatment	Rebates or exemptions on royalties, sales taxes, producer levies and tariffs	✓		
	Tax credit Accelerated depreciation allowances on energy-supply equipment	✓		✓
Trade restrictions	Quotas, technical restrictions and trade embargoes		✓	
Energy-related services provided directly by government at less than full cost	Direct investment in energy infrastructure	✓		
	Public research and development Liability insurance and facility decommissioning costs	✓ ✓		
Regulation of the energy sector	Demand guarantees and mandated deployment rates	✓	✓	
	Cross-subsidy to low power users (lifeline rate) Price controls			✓ ✓
	Market-access restrictions		✓	

Disability Adjusted Life Years

- One DALY can be thought of as one lost year of "healthy" life. The sum of these DALYs across the population, or the burden of disease, can be thought of as a measurement of the gap between current health status and an ideal health situation where the entire population lives to an advanced age, free of disease and disability. (Source: WHO)
- $DALY = YLL + YLD$

https://www.who.int/healthinfo/global_burden_disease/metrics_daly/en/

And so in all of these we can think in terms of different kinds of subsidy mechanisms. But when we talk in terms of cooking, it is needed for us to estimate when we think in terms of the environmental impact and the health impact. And one parameter which is used for this is the disability adjusted life years. So one disability adjusted life year is thought of as one lost year of healthy life.

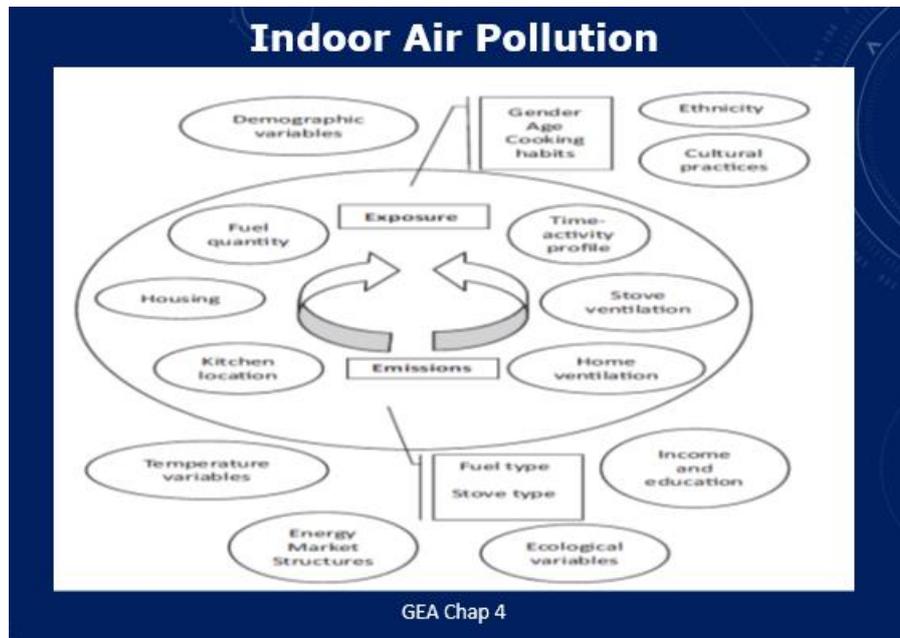
And the sum of these disability adjusted life years across the population, or the burden of disease can be thought of as a measurement of the gap between current health status and an ideal health situation where the entire population lives to an advanced stage free of disease and disability. This source is from the World Health Organization, you can see that this disability adjusted life year is the year of lost life and the lost days of work.

So what happens is because of disability, if people are not able to work at their full efficiency, and they have to take leave, so that is one and then if people die at a year which is before their expected life tenure. And so these are computed again in terms of based on the emissions, the health impact, respiratory diseases and the number of deaths and then in that population, statistically the age distribution were impacted, then for each one, the number of years lost and then that is multiplied by the population.

So, this is something you can get more details both in the World Health Organization as well as several papers which exist, but this is one way to quantify and in doing this, we can see how indoor air pollution compares with.

For instance, outdoor, air pollution or with actual diseases and their impacts and you find that it is in most countries, this is a very significant it comes in amongst the top few in terms of the health impact and this is something where we can see if we have a scheme where we can reduce the emissions, then we can adjust this and compare.

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So, there is this whole chain as we said emissions, then the exposure and this depends on a variety of things that means, what is the time activity profile, what is the ventilation of the stove and the home and what kind of fuel is there, location of the kitchen, gender, age and cooking habits, demographic variable, and the cultural practices, ethnicity, income and education, fuel type and stove type, energy market structures, temperature variable, so, there are a whole host of different parameters, and many of these can be affected by policies.

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Consider a poor rural household that uses three kerosene lanterns with the following data:

- a) cost of lamp Rs 100
 - Life 5 years
 - Annual O& M cost Rs 20/year
 - Usage: 4 hours/ day (20ml/hour)
 - Price of kerosene: Rs 35/ litre (market price)
 - 82% Carbon by weight (specific gravity 0.8)
- Replace by solar PV lantern:
 - Capital cost: Rs 550(life 10 years)
 - Rs 150 (battery -2 years)

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So, now let us look at taking some of these that means the earlier things that we have done and make a simple calculation to see what it means when we think in terms of looking at a switch of fields. So let us consider a poor rural household. It uses 3 kerosene lanterns with the following data. The cost of the lamp is Rs.100, life is 5 years, annual O & M cost is given as Rs.20/year.

The usage is 4 hours per day or 20 millilitres of kerosene per hour, price of kerosene market price has given us Rs. 35/litre. We are given that the kerosene is 82 % carbon by weight, specific gravity is 0.8, we want to replace it by solar PV lantern capital cost is Rs.550, life 10 years, Rs. 150, battery 2 years.

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- a) Consider a household that uses kerosene. Calculate the annual cost and the CO₂ emissions for each kerosene lantern and the viability of replacement with solar. (Use a residential discount rate of 60 %)
- b) Consider the impact of having a subsidy on kerosene (Rs 18/l). Does this affect the viability?
- c) Compute the cost of lighting for each solar lamp. If the model was to have a lease model, calculate the effective monthly payment. Use a government discount rate of 10%.
- d) If the effective household subsidy is to remain constant, suggest a model for capital subsidy for reductions in lease payments.

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The question that is asked is considering a household that uses kerosene, calculate the annual cost and the CO₂ emissions for each kerosene lantern and the viability of replacement with solar, user residential discount rate of 60%. So let us look at first household that uses kerosene, let us calculate the annual cost.

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Handwritten calculations on a whiteboard:

$$\begin{aligned} \text{ANNUAL KEROSENE USED} &= \frac{4 \times 20}{1000} \times 365 \\ &= 29.2 \text{ LITRES.} \\ (3 \times 29.2) &= 87.6 \text{ LITRES.} \\ 87.6 \times 35 &= \text{Rs } 3066 \\ &\quad \frac{60}{60} \\ &= \text{Rs } 3126 \\ \text{ANNUAL CO}_2 \text{ EMISSION} &= \frac{87.6 \times 0.8 \times 0.82 \times 44}{12} = 210 \text{ kg CO}_2 \\ &\quad \frac{70}{70} \end{aligned}$$

Annual cost will be and first let us calculate annual kerosene used and annual kerosene use is going to be there, 3 this is sorry. Let us see for any each of the let us do this first for each one. Each of these kerosene lanterns is used for 4 hours. Okay and in each hour it is using 20 millilitres, so 4 into 20 by 1000 into 365 days you should calculate this, you will get this as 29.2 litres of kerosene.

So that means, for the household if you are using 3 lanterns, 3 into 29.2 so 87.6 litres, and if we look at the cost this will be 87.6 into 35 comes out to be Rs 3066. We have also said that there is a operation maintenance cost of 20 rupees per lamp annually 16 so this comes to Rs.3126, fairly high amount. If we look at an annual CO₂ emissions, let us calculate annual CO₂ emissions.

This will be now we are using 87.6 litres into density 0.8 that is about that is this turns out to be 70 kgs, and each kg has 0.82 kg of carbon per kg of kerosene into C plus O₂ giving you CO₂ so 44 by 12, and this turns out to be 210 kg of CO₂, annual CO₂ we have calculated.

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- a) Consider a household that uses kerosene. Calculate the annual cost and the CO₂ emissions for each kerosene lantern and the viability of replacement with solar. (Use a residential discount rate of 60 %)
- b) Consider the impact of having a subsidy on kerosene (Rs 18/l). Does this affect the viability?
- c) Compute the cost of lighting for each solar lamp. If the model was to have a lease model, calculate the effective monthly payment. Use a government discount rate of 10%.
- d) If the effective household subsidy is to remain constant, suggest a model for capital subsidy for reductions in lease payments.

The next question was so, is it viable annual cost and the CO₂ emissions. So annual cost is Rs. 3126 and the CO₂ emissions is 210 kgs. So, viability of replacement with solar so when we look at a replacement with solar, we are looking at a total cost is Rs. 700 right, and Rs. 700 is saving us annually we are saving around Rs. 3000 so the payback period is less than a month, less than a year and so from that point it may be viable. However, if we now look at it in terms of it seems to be viable.

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Handwritten calculations on a whiteboard:

700Rs

$$\begin{aligned} \text{ALCC} &= 100 \text{ CRF}(0.6, 5) + 20 + 29.2 \times 35 \\ &= 100 \times 0.603 + 20 + 1022 \\ &= 1108 \text{ Rs.} \end{aligned}$$
$$\begin{aligned} \text{ALCC for solar} &= 550 \text{ CRF}(0.6, 10) + 150 \text{ CRF}(0.26, 2) \\ &= 550 \times 0.6055 + 150 \times 0.985 \\ &= 632 \text{ Rs} \\ &\quad \underline{652 \text{ Rs}} \end{aligned}$$

Let us look at it in terms of the annualized life cycle cost. If you look at the annualized life cycle cost of for 1 lamp, this is going to be 100 into capital recovery factor 0.6 and 5 plus 20 plus 29.2 into 35. And if you look at this, you will find that can calculate this as this turns out

to be 0.663 is Rs.1108, what is the annualized lifecycle cost for solar? This will be 550 into capital recovery factor 0.6, 10 years plus 150 which is the battery and we said battery life is just 2 years.

So, 0.6 and 2 plus we can add in both the cases that the Rs.20 is going to be there. So, this is 550 into 0.6055 plus 150 into 0.985 and this turns out to be Rs.632. If you add Rs.20 to this which is the O & M, Rs. 652. So obviously, the ALCC seems to be lower, even if we forget about this cost, that means instead of 1160, there is 1001 it is like 1000 and 652. So, from this point of view at full cost of kerosene, this does not look to be viable, this looks to be viable, solar looks to be viable.

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- a) Consider a household that uses kerosene. Calculate the annual cost and the CO₂ emissions for each kerosene lantern and the viability of replacement with solar. (Use a residential discount rate of 60 %)
- b) Consider the impact of having a subsidy on kerosene (Rs. 18/l). Does this affect the viability?
- c) Compute the cost of lighting for each solar lamp. If the model was to have a lease model, calculate the effective monthly payment. Use a government discount rate of 10%.
- d) If the effective household subsidy is to remain constant, suggest a model for capital subsidy for reductions in lease payments.

Handwritten calculations showing the cost of lighting and solar lamp lease payment:

$$18 \times 29.2 + 100 \times 0.663$$

$$Rs. 525.6$$

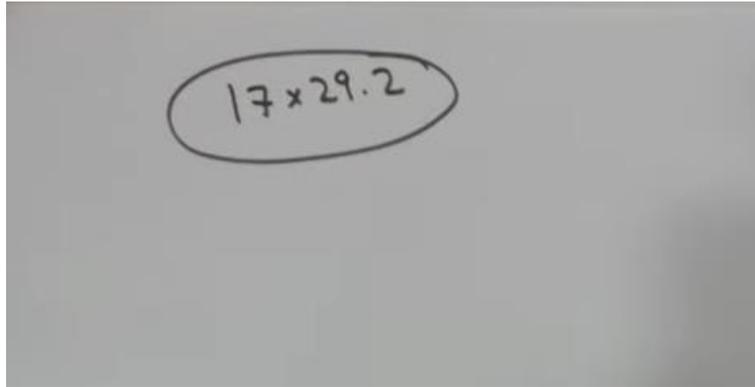
$$\frac{652}{12} \sim 54 Rs$$

$$102 \quad 550 CRF(0.1, 10) + 150 CRF(0.1, 2)$$

$$0.1627 \quad 0.576$$

$$= 2341 Rs$$

$$\frac{341}{12} \quad 25 Rs$$



A grey rectangular box containing the handwritten mathematical expression 17×29.2 circled in black ink.

If we compute can suppose there is a subsidy on kerosene and it is Rs.18/litre, then this will be 18 into 29.2. So, now this is Rs.525.6 this now, in when it is subsidized it is lower than the solar so it will not be viable to shift to solar once you have subsidized kerosene. And so, the question now is calculate the cost of lighting for each solar lamp. And if the model was to have a lease model calculate the effective monthly payment.

So, for each solar lamp if we look at it in terms of the calculation that we had done, it was 652 divided by 12 which is 560 and 5248 something like 54 or 55 Rs/month. So, that could be a way in which we could do this. This is of course with the high discount rate. If we calculated this with a societal discount rate of 10 % then this is going to be much lower because we are going to do 550 CRF 0.1, 10 plus 150 CRF 0.1, 2 and with the result that this is just going to be, you can calculate this you will find that this is Rs. 341.

And this is no point I think this is 0.167 and this is 0.1627, this is 0.576. So, if 341 divided by 12, something like Rs. 25, Rs. 26/month. And the advantage then is that this company which has the government or a public sector company, which has lower discount rate, now needs to only recover at the rate of Rs.25 /month.

And we can also look at if you see the subsidy that we had, the subsidy per lamp was now Rs. 17 into 29.2. So, you will see that we can also provide that subsidy, if we want to keep that subsidy constant we can even reduce the we can reduce the initial capital cost by that amount. And then we can have the we can reduce the lease payments so that means instead in in a month, we are only paying lower quantity. The advantage there now is that because of the higher discount rate, the household is not able to upfront pay that initial amount and is now able to just pay these monthly payments.

So, now the question then is the last part of the question is that would you recommend complete removal of the kerosene subsidy. And when we think about this the kerosene subsidy is also to

provide for kerosene is often useful cooking. And in some of these cases, for instance, if there is no, if there is a problem in terms of the battery and the solar, there will be an incentive for this.

There will be what will be the issues in implementation, there is a transaction cost of actually providing this, we need to provide support for maintenance and what are the disadvantages of the solar lantern, we have to ensure that the PV modules are kept in the sun, so that they get charged and then the usage pattern and the discharge.

So, there are we would need to have a hybrid where we still can maintain a certain amount of kerosene and this, but this gives you an idea of how we can look at policies and we can look at economic impacts of putting the subsidies. The kerosene subsidy is incidentally being phased out, but in most cases where we can calculate you can actually see that the solar subsidy replacing the kerosene subsidy by a solar subsidy makes a lot of sense.