**Energy Resources, Economics and Environment**
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**Lecture – 21 P2**
**Net Energy Analysis – Part 2**

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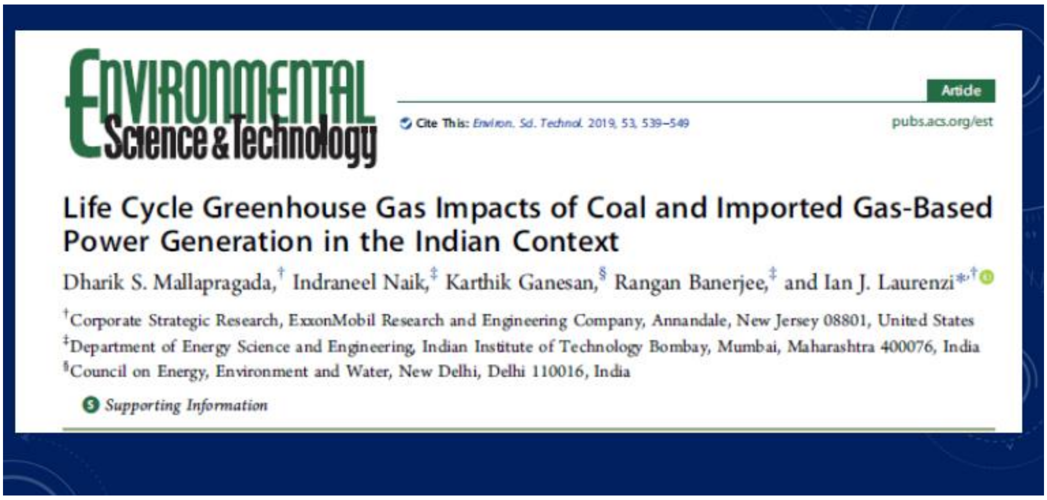


We had done a study and you may want to look at this study, where we had calculated the lifecycle greenhouse gas imp acts of coal based power plant and if we wanted to instead of coal, if we wanted to import natural gas through the LNG, basically liquefied natural gas import it from the US, look at the entire lifecycle of that and then see what happens in terms of the $CO_2$ point of view.

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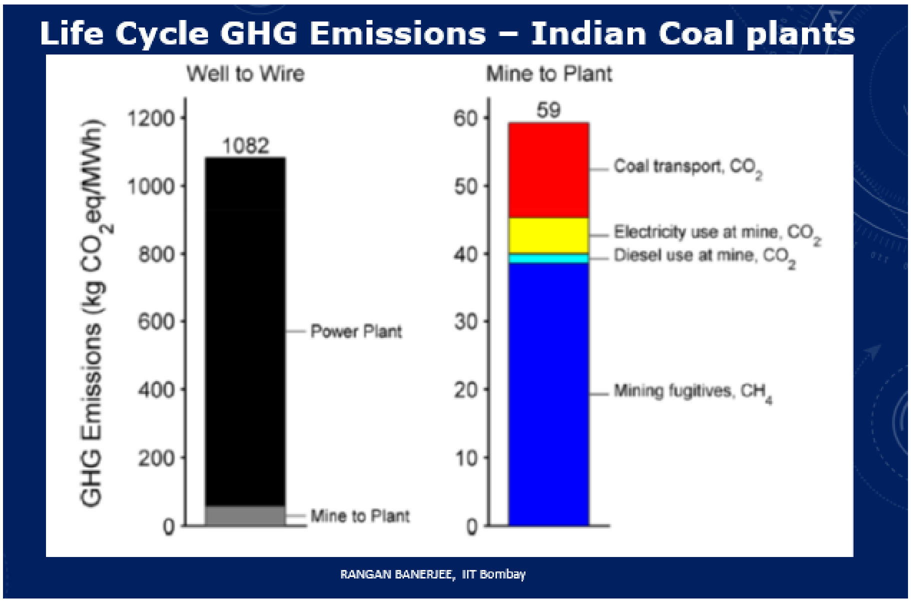

So, if we look at this, you will find that in the Indian context, the most of the as we saw, most of it is in the power plant itself, very similar to the Mann and Spath study. Here we got it as 1082 kg $CO_2$ equivalent per megawatt hour. Mine to plant has something coming in with the mining, at mining the CH4 emissions, fugitive emissions at the mine. Diesel and electricity use at the mind and the transport. So, this accounts for just 59 grams of 59 grams per kilowatt hour or 59 kg per megawatt hour. And so, this gives you a sort of break up, just from the, this is cradle to the gate kind of calculation.

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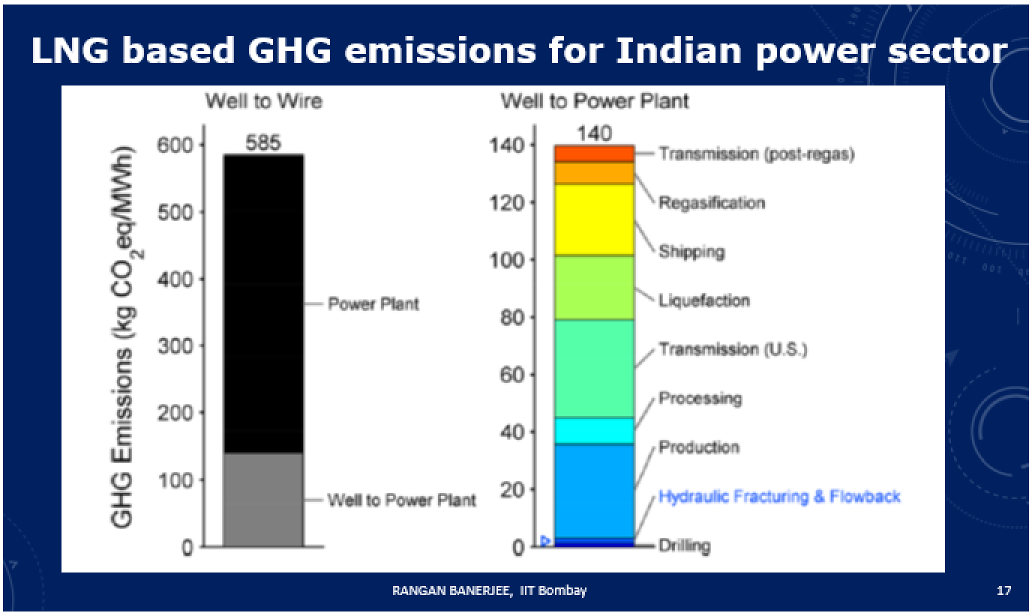


And if we look at a similar kind of thing for the, if we wanted to use imported natural gas, we find that the power plant accounts for much lower, the total comes down from 1000 to about 585. Here the well to power plant is significant of which it starts with the this is where they are looking at hydraulic fracturing and so, pack the production of the oil and then processing, the transmission in the US, liquefaction, shipping, regasification, that adds much more than the mine to, mine to the well.

As in the coal case, where we started from coal mining to the power plant that was very small, this is much higher, but then the actual operation is much lower. So, overall it turns out to be less.

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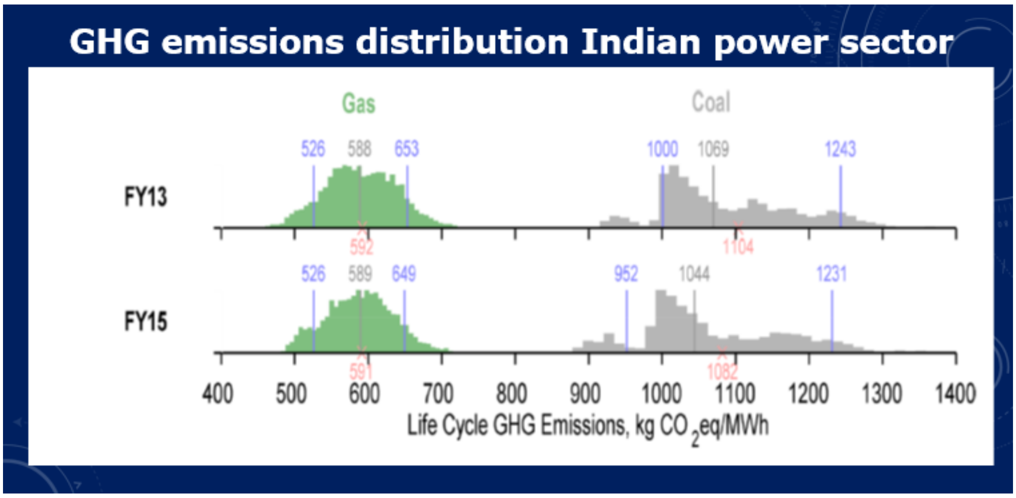


We also saw, based on this we made a distribution of the actual $CO_2$ emissions for the coal fleet of the Indian, of India and you can see very clearly that the mean is around this. There are some plants which are, which are more efficient, maybe there are the supercritical ones, and there are some which are operating with a much poorer emission record. And in the case of natural gas, if we had this kind of distribution, you can see that the mean will be much lower than this. So, this gives you an idea of what are the kind of GHG emissions for the power sector and how we can look at it from an energy point of view.

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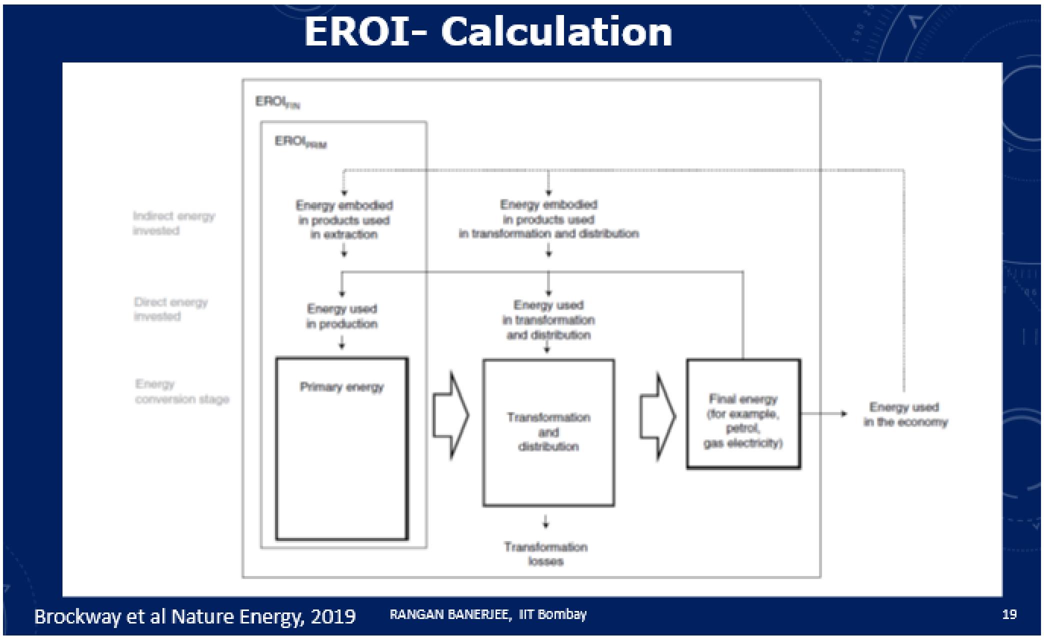


When we look at energy return on investment, there is a recent paper in nature energy which you may want to look at, which calculates the EROI and shows EROI for different kinds of different sources, including renewables. So, we can look at the energy EROI based on primary will be whatever energy is used in the extraction and the production, but we can also look at the energy embodied and used in transmission and distribution and the final energy. So, finally, if we look at this as the framework, the EROI values that we would get would be lower than that we have, we would get only if we looked at the primary.

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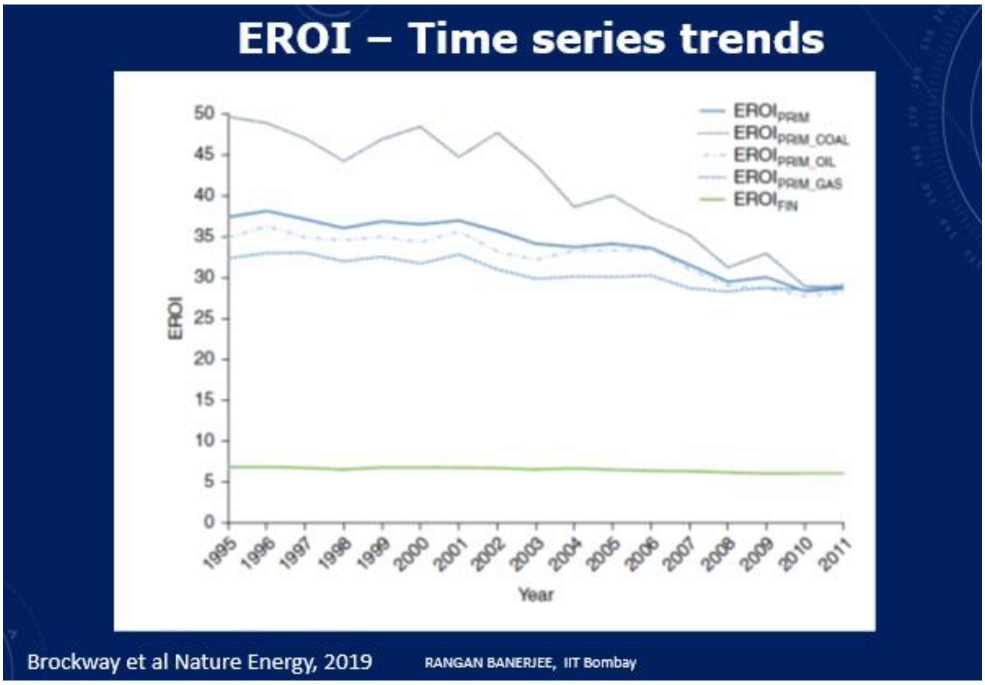


So, if we see this, this paper shows the EROI primary and the EROI final. And you can see over a period of time that the EROI's have been coming down. And finally, EROI is we are talking of are of the order of about 30 or so which is also pretty high number.

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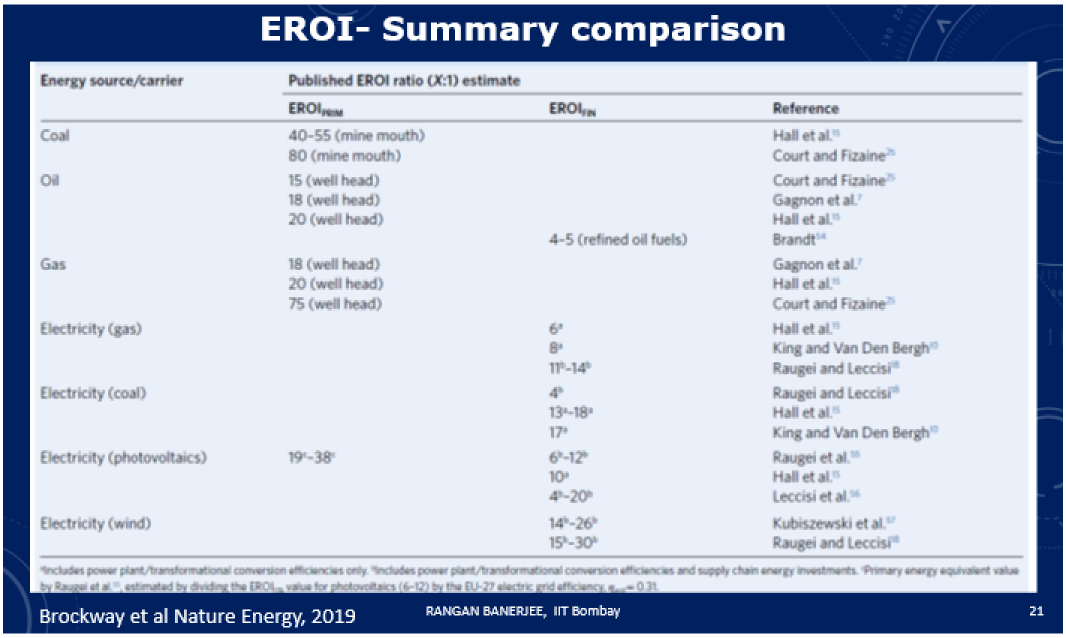

# EROI- Summary comparison

| Energy source/carrier | Published EROI ratio (X:1) estimate | | |
|---|---|---|---|
| | $EROI_{PRIM}$ | $EROI_{FIN}$ | Reference |
| Coal | 40-55 (mine mouth) | | Hall et al.[15] |
| | 80 (mine mouth) | | Court and Fizaine[25] |
| Oil | 15 (well head) | | Court and Fizaine[25] |
| | 18 (well head) | | Gagnon et al.[7] |
| | 20 (well head) | | Hall et al.[15] |
| | | 4-5 (refined oil fuels) | Brandt[54] |
| Gas | 18 (well head) | | Gagnon et al.[7] |
| | 20 (well head) | | Hall et al.[15] |
| | 75 (well head) | | Court and Fizaine[25] |
| Electricity (gas) | | 6[a] | Hall et al.[15] |
| | | 8[a] | King and Van Den Bergh[10] |
| | | 11[b]-14[b] | Raugei and Leccisi[18] |
| Electricity (coal) | | 4[b] | Raugei and Leccisi[18] |
| | | 13[a]-18[a] | Hall et al.[15] |
| | | 17[a] | King and Van Den Bergh[10] |
| Electricity (photovoltaics) | 19[c]-38[c] | 6[b]-12[b] | Raugei et al.[55] |
| | | 10[a] | Hall et al.[15] |
| | | 4[b]-20[b] | Leccisi et al.[56] |
| Electricity (wind) | | 14[b]-26[b] | Kubiszewski et al.[57] |
| | | 15[b]-30[b] | Raugei and Leccisi[18] |

[a]Includes power plant/transformational conversion efficiencies only. [b]Includes power plant/transformational conversion efficiencies and supply chain energy investments. [c]Primary energy equivalent value by Raugei et al.[55], estimated by dividing the $EROI_{FIN}$ value for photovoltaics (6–12) by the EU-27 electric grid efficiency, $g_{grid}$ = 0.31.

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This is a summary of different studies, EROI estimates and you can see here that the EROI estimates show for electricity for photovoltaic, the EROI final which we are talking of are of the order of 6 to 20, again depending on the different kinds of studies and the different kinds of estimates and assumptions which are there.

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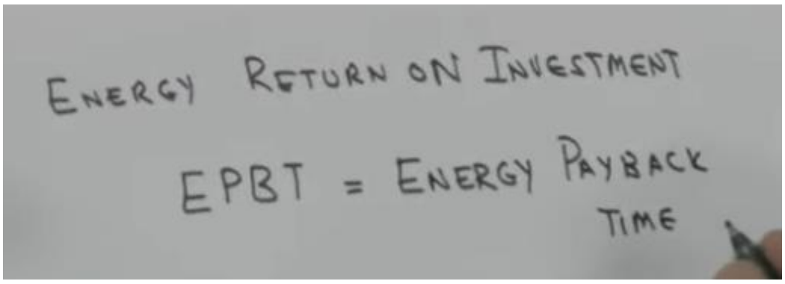


In addition to the EROI there is another EPBT, which is basically energy payback time. So, if we look at the total amount of embodied energy in let us say a solar PV module, and see how much time does it take for us to generate that much energy.

So, in the 1970s and 1980s the energy payback periods of photovoltaic was high, which meant that it would take a large number, large number of years for that energy to pay back and for any new source which we consider as renewable, we can calculate this and see whether or not it is viable. So, apart from the EROI, we have another index called the energy payback period.

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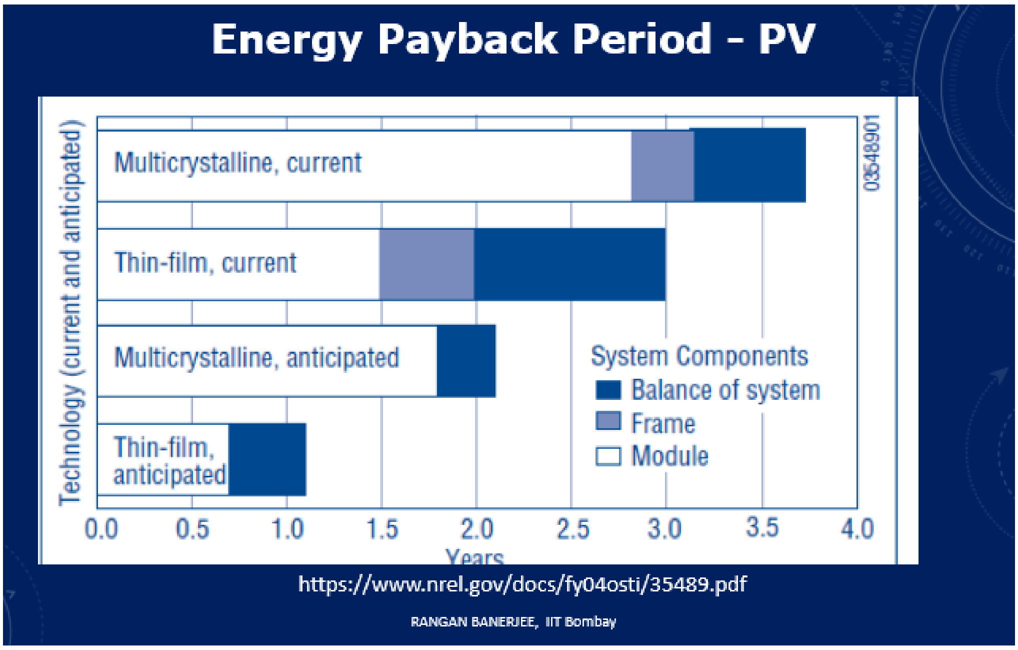


So, this is from an NREL report, you can see this NREL if you look at this document, it shows you the kind of energy payback periods for the entire PV system, which is of the order of three years or less.

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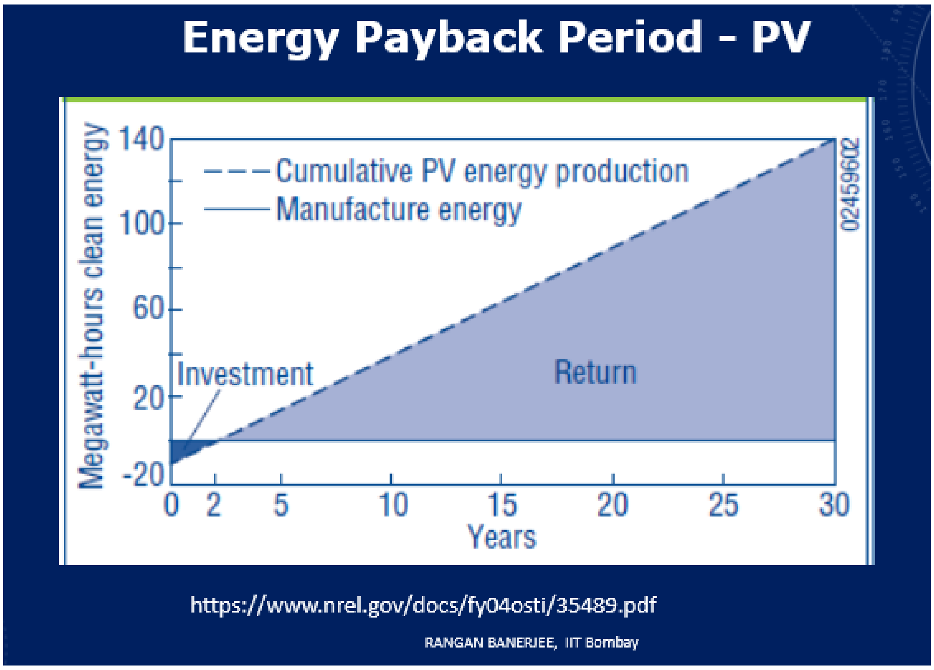


And we can look at this data it happens this way that we put in all the energy in the initial period, this is when we build the PV cells, balance of systems and then you get the returns over the years and that is, that is gives you the.

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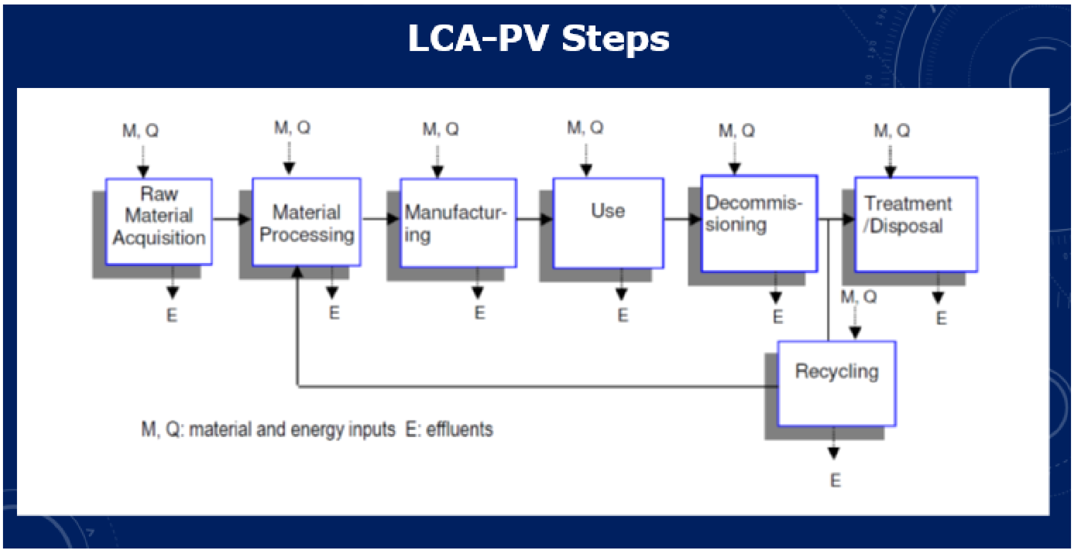


So, when we look at the earliest environmental impact, systematic environmental impact of photovoltaic, was done by Alsema and you can look at this paper in 2000, start with the raw materials, go to the material processing, the manufacturing, the use, the decommissioning, as well as some of it is recycled and then the treatment and disposal.

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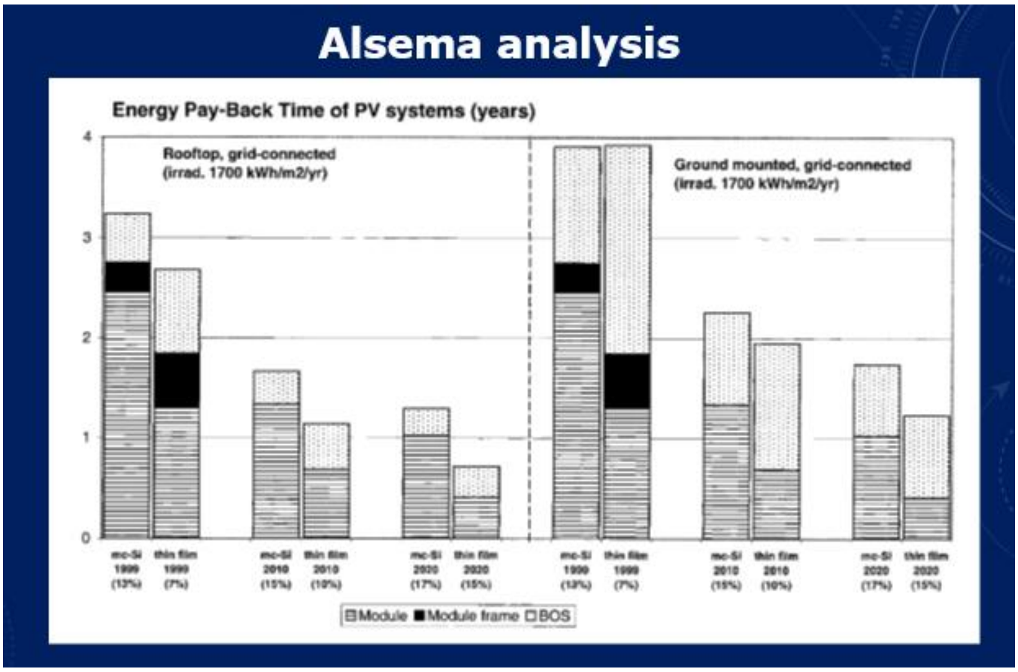


And with this, the energy payback periods that were done for rooftop and ground mounted systems. Of course, this will depend on these solar installations and the efficiencies. And based on this, you can see that these payback periods are of the order of two to three years again depending on the kind of assumptions.

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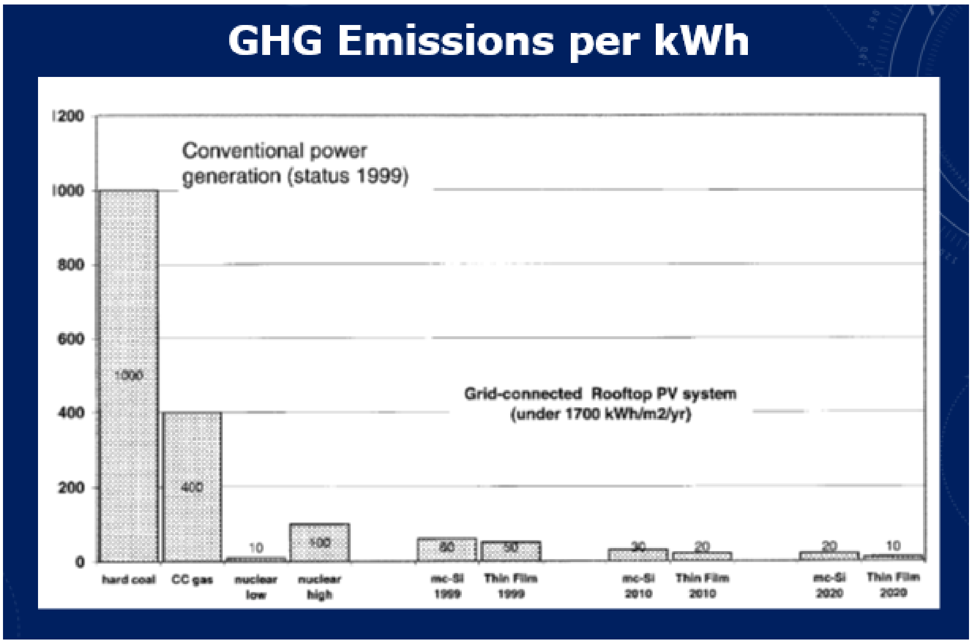


You can look at this paper and this will give you based on this, we can also look at the GHG emissions and you can see, we had seen this in the initial phase where we talked about the chia identity and we said that, renewables are an option for us to reduce the GHG emissions, we said, as compared to 1 kg of $CO_2$ /kWh roughly for coal.

When we talk of all the renewables, they are all in the range of 20, 30 grams per kilowatt hour. And so, this is, these numbers are got from this life cycle analysis, and one may look at this in a little more detail.

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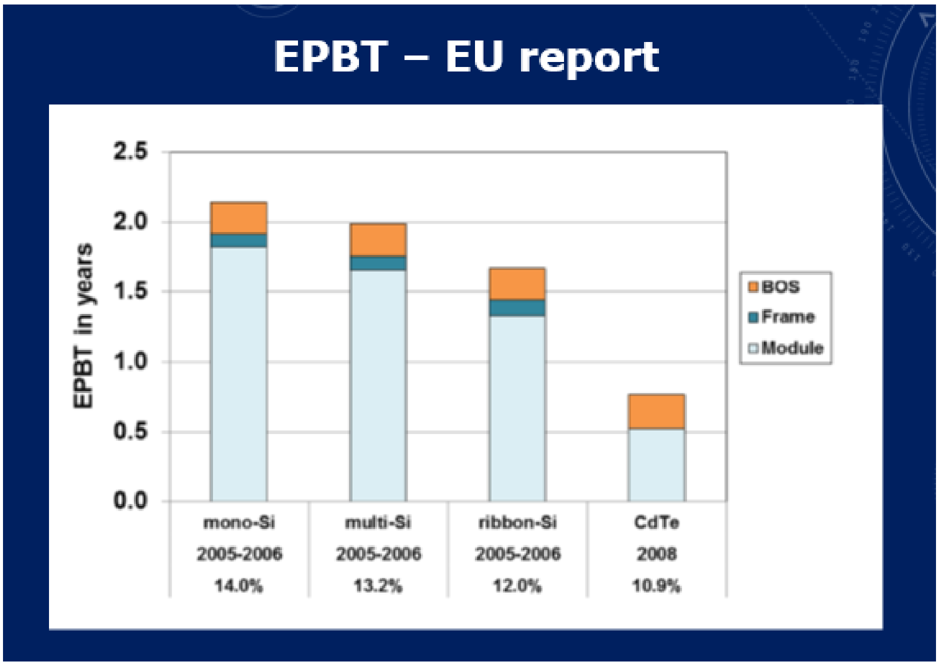


And there is a recent report from the European Union, which talks about the energy payback period of the recent cells. Again, with different kinds of efficiencies, mono crystals, silicon, if you see, it turns out to be of the order of about two years. And then the similar things you can look at multi silicon, cadmium telluride and so on.

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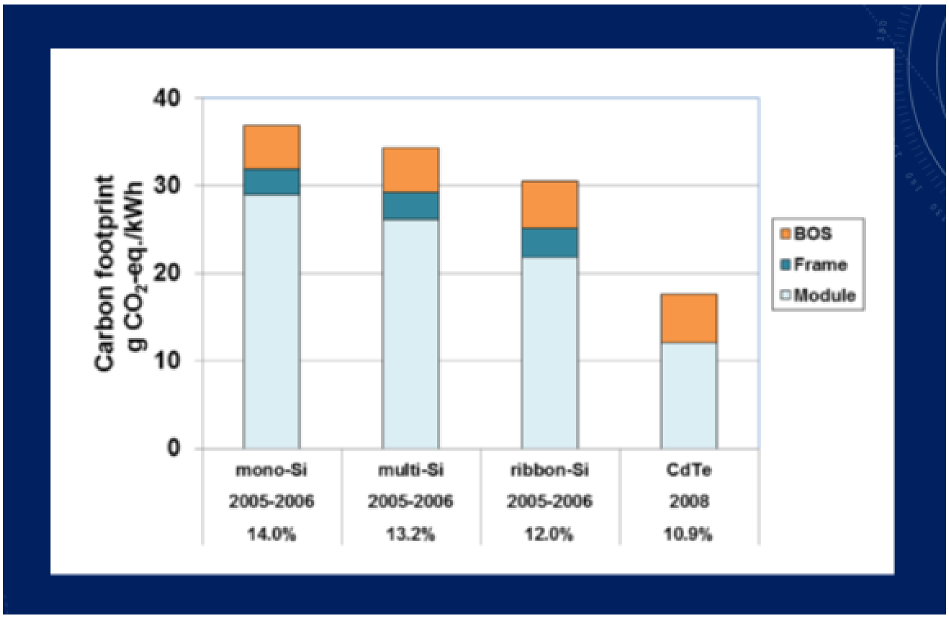


This this also gives you an idea of the total carbon footprint. We have later I will show you some numbers that we have done for an Indian context on a similar basis.

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| Impact Category | Scale | Relevant LCI Data | Common Characterisation Factor | Description of Characterisation Factor |
|---|---|---|---|---|
| Global Warming | Global | Carbon Dioxide ($CO_2$)<br>Nitrous Oxide ($N_2O$)<br>Methane ($CH_4$)<br>Chlorofluorocarbons (CFCs)<br>Hydrochlorofluorocarbons (HCFCs)<br>Methyl Bromide ($CH_3Br$) | Global Warming Potential | Converts LCI data to carbon dioxide ($CO_2$) equivalents<br>Note: Global warming potentials can be 50, 100 or 500-year potentials |
| Stratospheric Ozone Depletion | Global | Chlorofluorocarbons (CFCs)<br>Hydrochlorofluorocarbons (HCFCs)<br>Halons<br>Methyl Bromide ($CH_3Br$) | Ozone Depleting Potential | Converts LCI data to trichlorofluoromethane (CFC-11) equivalents |
| Acidification | Regional<br>Local | Sulphur Oxides (SOx)<br>Nitrogen Oxides (NOx)<br>Hydrochloric Acid (HCL)<br>Hydrofluoric Acid (HF)<br>Ammonia ($NH_4$) | Acidification Potential | Converts LCI data to hydrogen ($H^+$) ion equivalents |
| Eutrophication | Local | Phosphate ($PO_4$)<br>Nitrogen Oxide (NO)<br>Nitrogen Dioxide ($NO_2$)<br>Nitrates<br>Ammonia ($NH_4$) | Eutrophication Potential | Converts LCI data to phosphate ($PO_4$) equivalents |
| Photochemical Smog | Local | Non-methane volatile organic compounds (NMVOC) | Photochemical Oxidant Creation Potential | Converts LCI data to ethane ($C_2H_6$) equivalents |
| Terrestrial Toxicity | Local | Toxic chemicals with a reported lethal concentration to rodents | $LC_{50}$ | Converts $LC_{50}$ data to equivalents |
| Aquatic Toxicity | Local | Toxic chemicals with a reported lethal concentration to fish | $LC_{50}$ | Converts $LC_{50}$ data to equivalents |
| Human Health | Global<br>Regional<br>Local | Total releases to air, water and soil | $LC_{50}$ | Converts $LC_{50}$ data to equivalents |
| Resource Depletion | Global<br>Regional<br>Local | Quantity of minerals used<br>Quantity of fossil fuels used | Resource Depletion Potential | Converts LCI data to a ratio of quantity of resource used versus quantity of resource left in reserve |
| Land Use | Global | Quantity disposed of in a landfill | Solid Waste | Converts mass of solid waste into volume using an estimated density |

When we look at the final lifecycle analysis, normally you can actually use your own calculations, you can do this on with an Excel spreadsheet or you can use MATLAB many, many of the researchers do use software for LCA and there are a number of software Simapro, Gabi, some of them are public domain software like open LCA. The advantage of the software often is also that they have databases which are available for different kinds of materials and that will reduces the kind of time that you need to make the analysis.

Please also remember that these databases which are there for the embodied energy will have assumptions, will be based on a certain kind of mix, will depend on the country for which it is there, so, if you are doing something for India please make sure you know how that when you use an embodied energy for some materials, find out for which country or context it is there and is in the Indian context is it going to be similar?

You will find in all of these software you will find that there are multiple criteria which are calculated including the different kinds of. So, there are different environmental emission factors which are there and then the emissions are computed, both local, global, so, you can see that are criteria for global warming which is $CO_2$, N2O, methane, CFC and then this can be converted into a $CO_2$ equivalent.

And there are ozone depletion criteria’s like CFCs, HCFCs and then there are acidifications, SOX, NOX, hydrochloric, hydrofluoric acid, eutrophication, and local photochemical smog, all of this, the toxicity, all of these parameters are there and one gets in the one gets a whole set of multiple criteria.

Now, depending on your application, we have to look at these criteria, see whether they are beyond the limits, compare the criteria across different options and then take, then look at the implication in terms of a decision.

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| Type of impact | Combustion based | | | | Nuclear | Hydro | Wind | Solar |
|---|---|---|---|---|---|---|---|---|
| | Coal | Oil | Gas | Biomass | | | | |
| Resource depletion | X | X | X | | X | | | |
| Land use, visual impact | (X) | | | X | | X | X | X |
| Watercourse regulation | | | | | | X | | |
| Thermal releases | X | X | X | X | X | | | |
| Noise | | | | | | | X | |
| Radiation | | | | | X | | | |
| Air quality | X | X | X | X | | | | |
| Acidification | X | X | X | X | | | | |
| Eutrophication | X | X | X | X | | | | |
| Greenhouse effect | X | X | X | X | | | | |

So, in many of these cases. So, basically what happens is this this is from the IEA's, assessment LCS, assessment of different sources and you can see what all are the adverse impacts for different kinds of sources and then these can be quantified one can see what kind of tradeoffs one can have.

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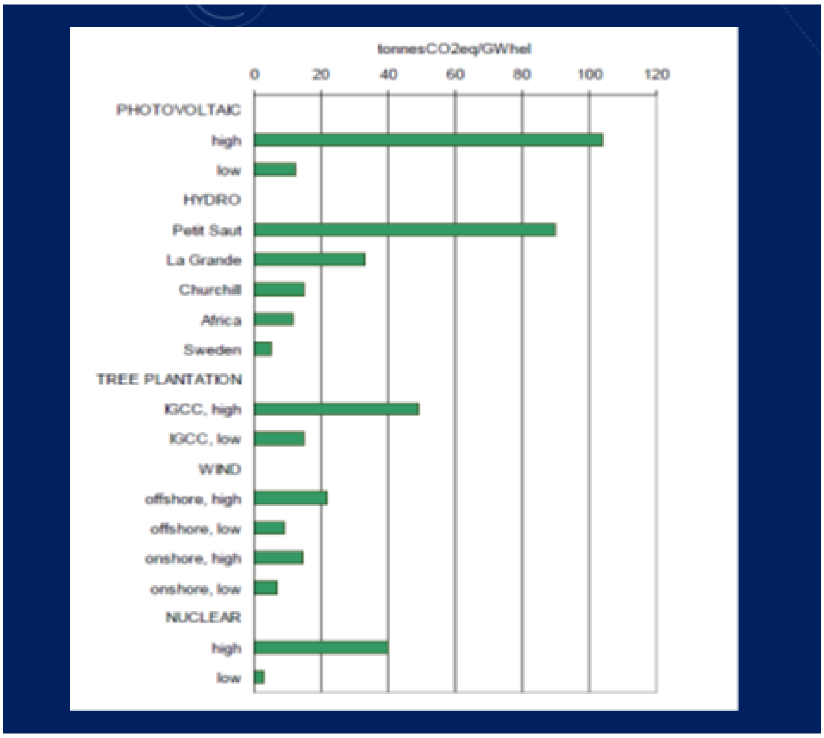


Similar this is the LCA assessment report in terms of this is from the World Energy Council and you can see that this has the different kinds of $CO_2$ equivalent, tons of $CO_2$ equivalent per Gigawatt hour. And you can compare the impacts which are there for nuclear, for wind and for photovoltaics.

There are LCA has been traditionally, has been very useful in seeing for instance, when we link think in terms of replacing oil, we have been thinking in terms of using biofuels. And there are number of different sources of biofuels, one can use biofuels based on waste, one can also have dedicated plantations for biofuels.

And several countries, including US and Latin America have been having large energy plantations. And sometimes what happens in these energy plantations is one puts in a significant amount of energy in the in the fertilizers, in the agriculture, in the irrigation, and when you look at the overall it may or may not be net energy positive. So, there have been situations where there is a subsidized and so it looks like it is a viable option, it is renewable, but when you do the numbers, you find that this is net energy negative.

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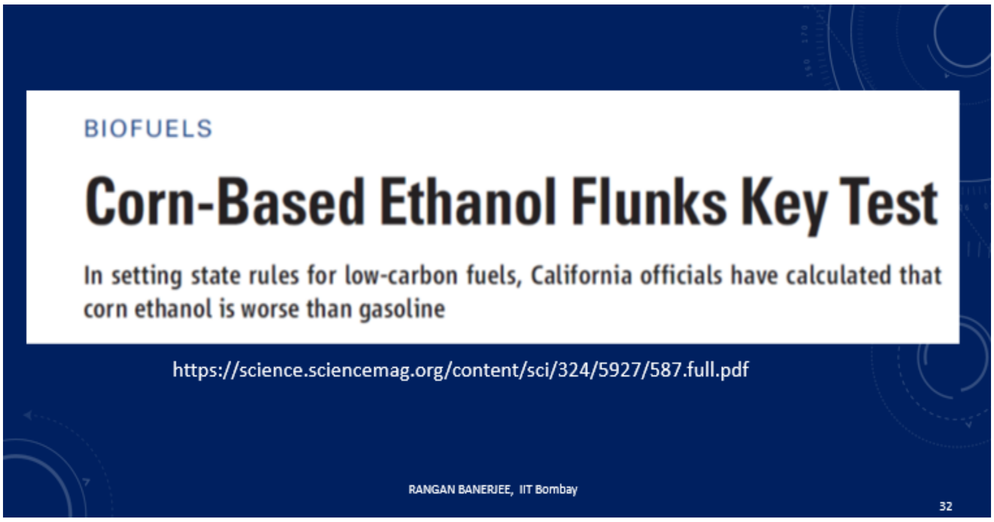


So, this is an example from a report, which is from science, where in the state of California, they assess that corn-based ethanol is net energy negative and is actually worse than gasoline, gasoline is the fuel which is used for vehicles in the US.

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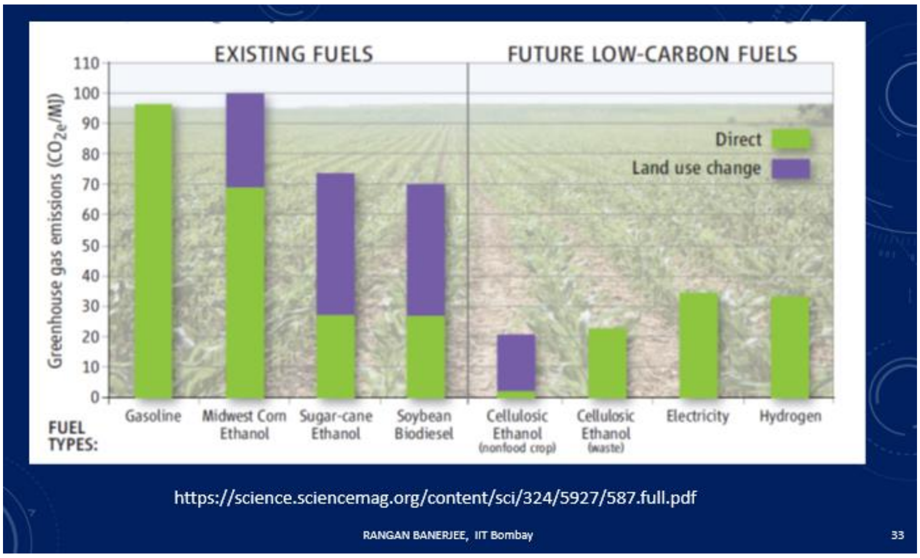


And if you look at it, this is the greenhouse gas emissions from gasoline, in terms of equivalent $CO_2$, equivalent per mega joule of the fuel. And when we look at corn ethanol, there is a direct emission and then there is an emission which is because of the land use change. And when you add this up, you can see that this turns out to be a worse.

And so of course, these are interesting because in as we will see, when we talk about policy analysis. Policymakers usually like to have a solution which is a large-scale solution. So, we want to have a large amount of Corn Ethanol or we want to have a large amount of Jatropha.

And then, because it seems to be renewable, one subsidizes it, but then maybe in some cases, this does not result in the impact that you expect and you are actually putting in more energy, you are actually putting in more emissions than you would have done if you just continued with the gasoline case.

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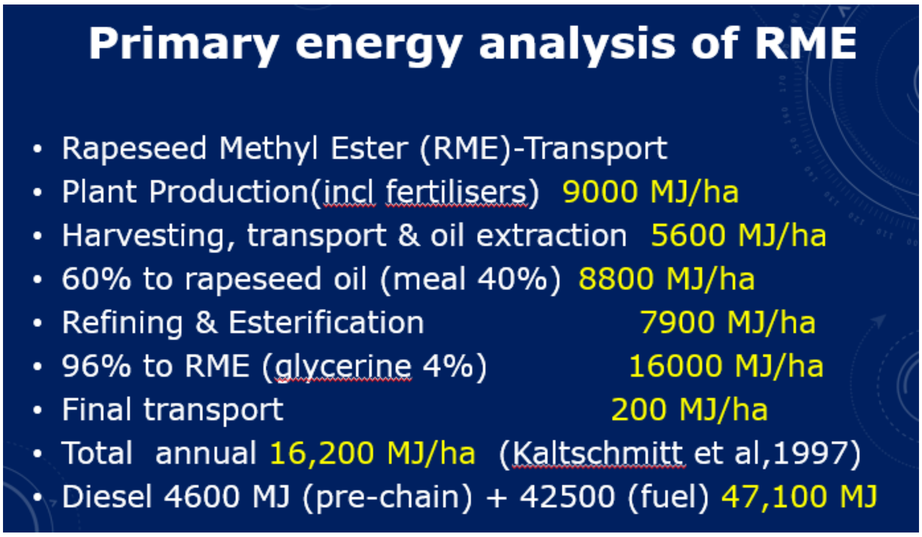


So, this is now a study for Germany. You can look this is a paper by Kaltschmitt, where a biofuel rapeseed methyl Ester for transport is calculated and the way it is calculated you can see the paper to get the numbers, but just to show you what it means is that the total energy that you are getting per hectare. And this we are looking at plant production including fertilizer, harvesting, transport, oil extraction, and some percentage is going to, is attributed to the rapeseed oil which is being used for our fuel.

And then refining esterification, some percentage going to be, this is what I meant when we talked about the allocation. So, 96% going to this, 4% going to the other byproduct glycerin and then final transport. So, the total annual comes to about 16,200 MJ/ha and if we look at this, so, per hectare this is the amount that we will get and this can be compared with the energy content which we are using for diesel and we can then compare these again in terms of the emissions.

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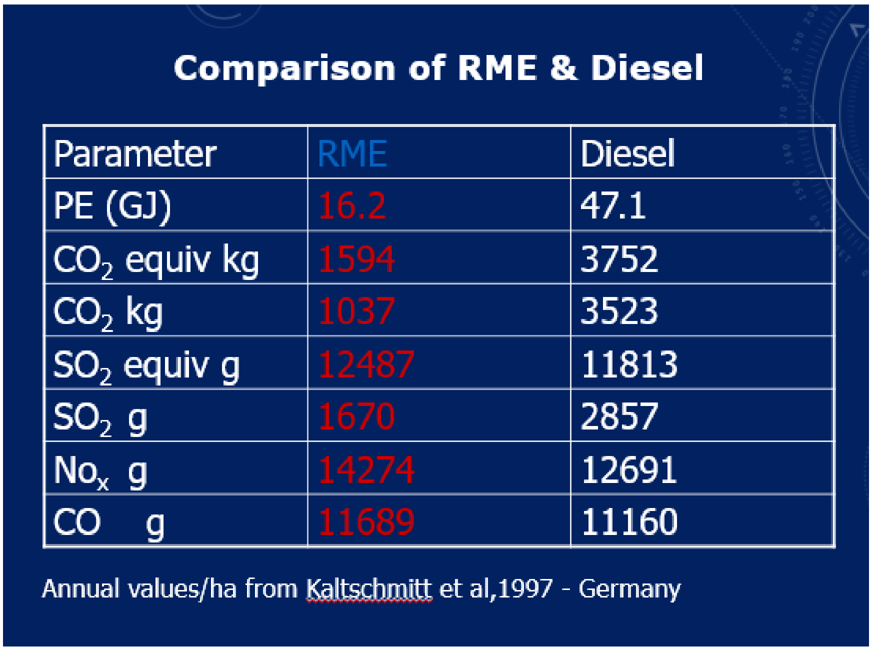
Comparison of RME & Diesel

| Parameter | RME | Diesel |
|---|---|---|
| PE (GJ) | 16.2 | 47.1 |
| $CO_2$ equiv kg | 1594 | 3752 |
| $CO_2$ kg | 1037 | 3523 |
| $SO_2$ equiv g | 12487 | 11813 |
| $SO_2$ g | 1670 | 2857 |
| $No_x$ g | 14274 | 12691 |
| CO g | 11689 | 11160 |

Annual values/ha from Kaltschmitt et al,1997 - Germany

So, this comparison which was done in terms of primary energies, this is 16.2, 47.1 is diesel, the $CO_2$ equivalent is 1594, and diesel is 3752. And so overall you can see, they could be in this it is, it looks like this is a viable option in terms of at least primarily it passes the test of emissions and energy.

So, let us look at now another example which is from an Indian context, we had carried out there was a period when the government was very keen on having large scale Jatropha plantations. And at that time, we thought that it would be worthwhile it would be interesting to see, so there was the entire map of India you would see that there was a plan to have a large amount of Jatropha plantations. And one of the things which we felt at that time was that one needs to analyze and see whether or not this is a viable option.

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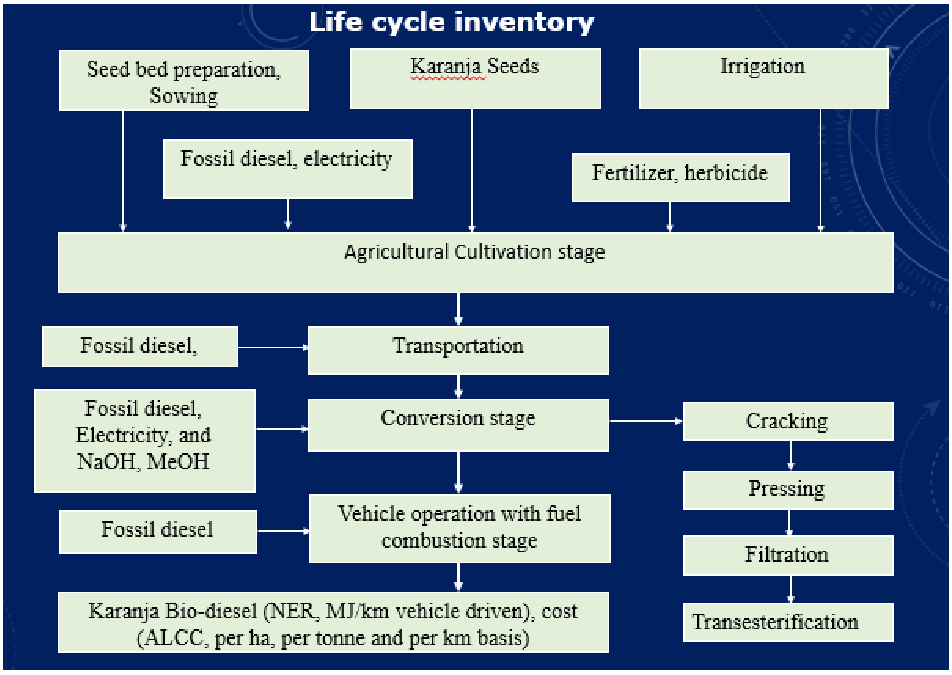


So, this is the work done by one of our students who was interning in summer and we compared both Jatropha and another one which is Karanja, Karanja is a seed which is used in often in south India. You can look at Jatropha or Karanja and we start with the first phase which is the agricultural cultivation phase. In the agricultural cultivation phase, there is some energy going into seed bed preparation sowing, there is some fossil energy going into diesel and electricity and there is energy going into the irrigation and fertilizers and herbicides, so that is the agricultural cultivation state.

We then take that and transport then transport we are using some fossil and diesel. Then we have the conversion stage, where you have the cracking, pressing, filtration, transesterification. And then we have the fossil which is used in vehicle operation stage.

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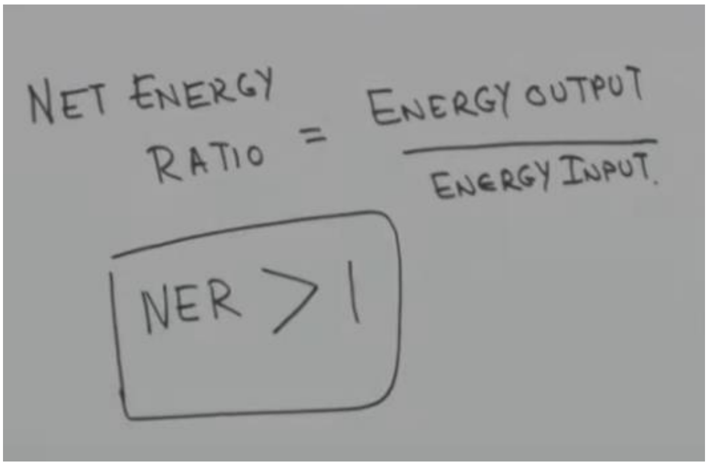


And based on this we calculated using the net energy ratio and net energy ratio this is another energy output, energy input and in this we do not take we are only taking for the energy input, we are not considering the energy that is put in with the biomass, we are only looking at only the fossil input.

So, this net energy for it to be viable, the net energy ratio must be greater than 1. And we can also calculate what is the mega joules per kilometer of vehicle driven, we can look at also the costs on a per ton and a per kilometer basis.

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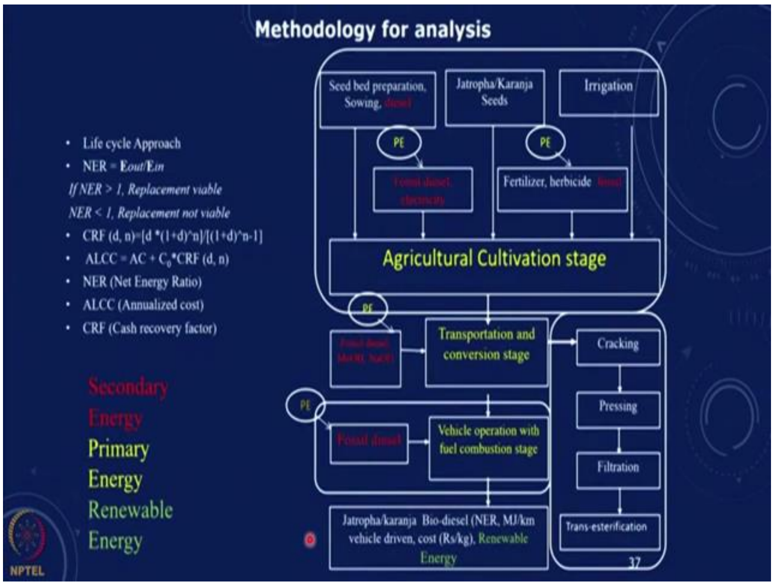


So, when we did this, if you see this we had primary energy which was going in here, primary energy going at this point and then we head the transportation and cracking stage and for Jatropha and Karanja. So, we did the life cycle approach and we looked at energy output by energy input, NER greater than 1, the replacement would be viable prima facie, then we have to look at the economics of course, NER less than 1, replacement not viable.

Then we did the lifecycle cost, then annualize lifecycle cost and calculated. So, we can calculate based on primary energy, on the renewable energy and secondary so you would like to see.

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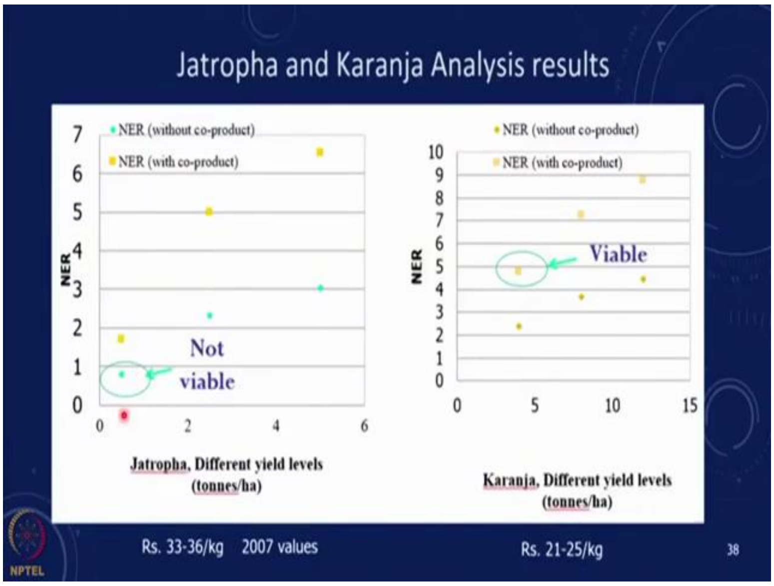


And the interesting thing is please look at this graph, these are all 2007 values. You can see that there are different, there are different kinds of combination depending on the yield and depending on the nature of the land. So, if you are using fallow land which has relatively low yields, we are need to put in much more of irrigation and fertilizers and there are situations where in the case of Jatropha where this is less than 1.

So, the other cases where the yields are higher and we can actually get this is without this is without the co-product, of course if we are using the co-product, which is and we can actually market that and that has a value then of course it becomes greater than 1 for all cases, but if we are not using the co-product which is glycerol, then you see that it depends on the kind of land.

So, if your yield is high then of course we are getting a NER of the 3 and in this case what happens is that, this is land, which is typically fertile land and so there is an issue of food versus fuel.

In the wastelands where we are looking at if you put Jatropha, you would find that it is not viable, we are putting in much more energy than it requires. And then so this is the kind of case, of course, this is the kind of price that we get and the prices was is similar, slightly higher than the price of the fuel that we are getting ex refinery at crude.

In the case of Karanja, we find that the situation is slightly better that is going to be viable in all the cases. So, whatever we looked at, we have looked at life cycle analysis, and net energy analysis, and we have looked at how to apply these and we have looked at a couple of examples. In the next module, we will take a few more examples to illustrate the use of net energy analysis and lifecycle analysis.