System Design for Sustainability
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Module - 09
Lecture – 04
LCA of a PSS

Hello, everyone, today's lecture will be on LCA of a PSS. So, what we will discuss today is about the different viewpoints and different approaches which various researchers working in the of LCA or PSS have taken on combining these two fields together. There is still no one guideline or framework on how to apply LCA to PSS hence we will take this kind of route.

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So, we will be discussing about the challenges of, applying LCA to evaluate a PSS that will give you an idea why there is lack of consensus. Then we will go to the elements of a LCA framework for PSS then, we will take each of these elements and discuss the challenges of each of the elements because of the variation in which LCA was first conceptualized LCA was conceptualized keeping in mind and that of a evaluation system for products. Of course, in the definition they buy products they mean it could be, products it could be services.

But, the challenges and PSS come because it is a combination of products and services and together they need to be evaluated.

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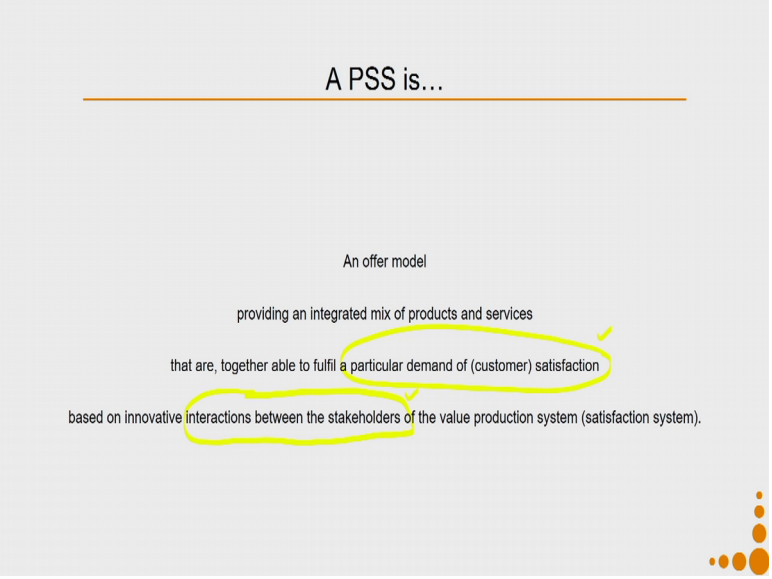

So, again a quick recap we already know PSS is an offer model, providing an integrated mix of products and services that are together able to fulfill particular demand of customer that is the satisfaction. Based on innovative interactions between the stakeholders of the value production system that is a satisfaction system.

So, here you can see, an important component is the interaction between the stakeholders. So, we will discuss, how this particular interaction between the stakeholders. Secondly, particular demand which is the satisfaction, where the problem of defining the functional unit for the life cycle and an lessers comes in this particular lecture.

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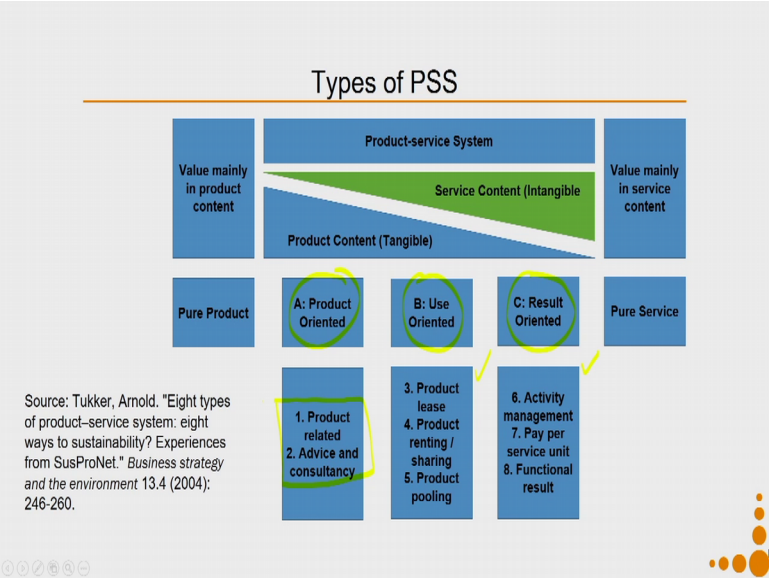

So, again we have discussed that, there were three types of PSS; the product oriented PSS, the use oriented PSS, the result oriented PSS. Since in the product oriented PSS the product component is still very large as compared to the use oriented or the result oriented; the problems and the complexities involved in conducting and else here keeps on changing across all these three typologies of PSS.

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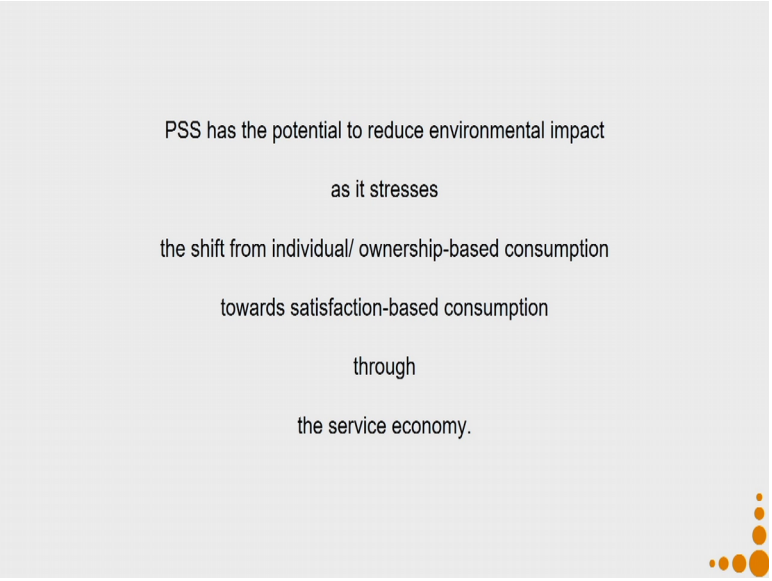

So, PSS has the potential to reduce environmental impact how is that achieved because, it stresses the shift from individual or ownership-based consumption, towards

satisfaction-based consumption through the service economy. So, in our previous lectures when we are talking about the MSDS methodology we use the radar diagram, we use various matrices over there all of them the qualitative matrices to check the degree of environmental impact improvement or the social impact improvement or the economic impact improvement.

So, now PSS although has a potential to reduce, environmental impact because it is saying that no longer, you have to produce too many products, which is required in the case of individual consumption. But, we move more towards the service industry, this particular model does not guarantee environmental impact will certainly get reduced.

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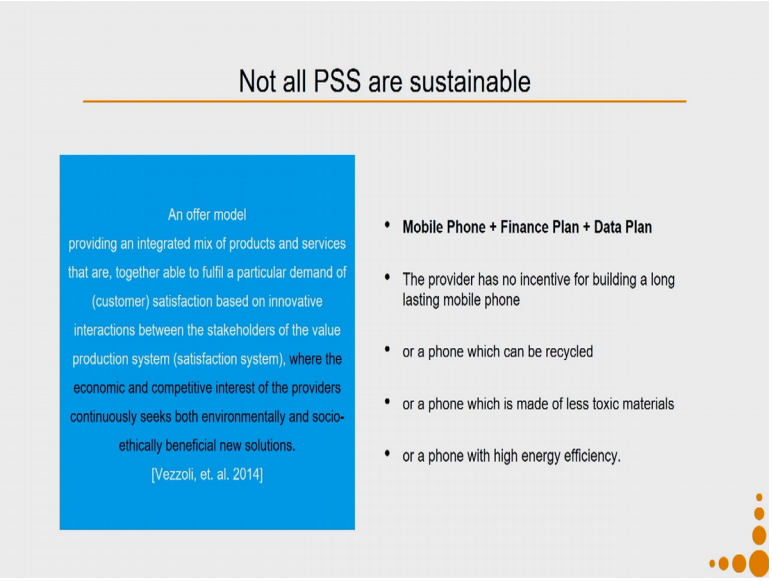

So, we discussed although, this also this example where you get a mobile phone plus a finance plan plus a data plane plan so, you have a product along with a service. But, in this particular formulation of PSS the provider has no incentive for building a long lasting mobile phone or a phone which can be recycled or a phone which is made of less toxic materials. So, in although this is also a PSS offering but, it does not bring in environmental benefits hence environmental benefits is not a guaranteed.

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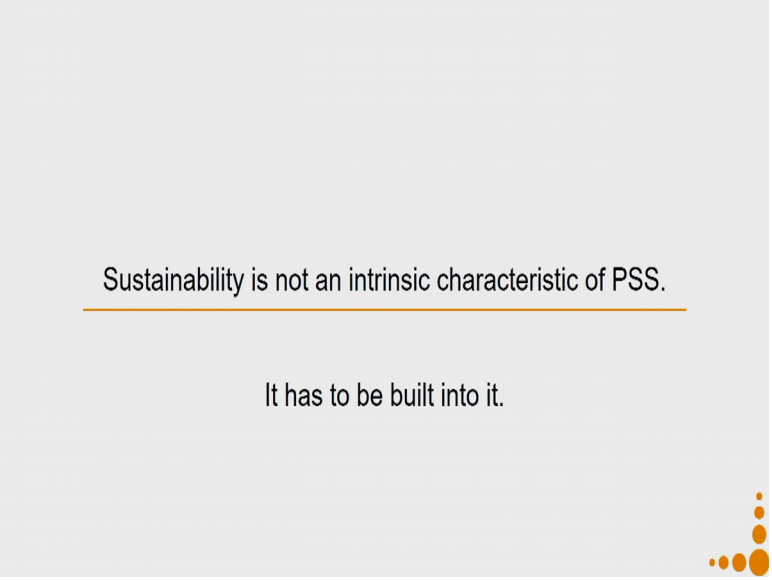

So, sustainability is not an intrinsic characteristic of PSS it only offers higher potential. Now, how do we design it? That determines whether we can build in Sustainability characteristics into PSS or not. So, our entire discussion on using the MSDS methodology will help you, in trying to build in the various Sustainability parameters into a PSS. Now, at the end of using the MSDS methodology, we used a SDO toolkit to evaluate our design concepts.

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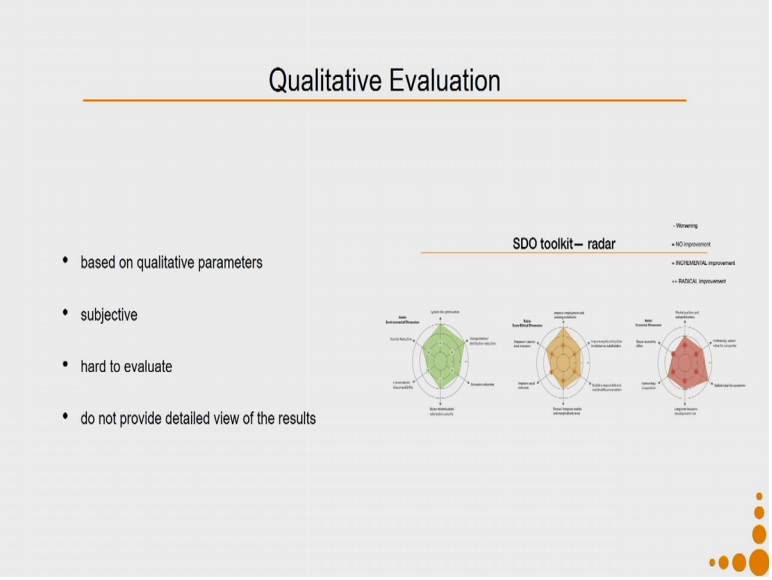

This is a qualitative evaluation tool of course it is a very useful tool because, it gives you easy access an easy way to compare between the various parameters check the improvements and worsening; but all these are qualitative in evaluation. So, they are based on qualitative parameters, they are subjective. So, I might say that there has been an radical improvement in the transportation or there has been a reduction in the distribution impact.

But, there might be others who might have a contrary way of looking added and all this way of looking added is a subjective judgment at that point of time they none of them are quantitative judgment. This is also very hard to evaluate there as so, as we were discussing during the lifecycle assessment design you might, assume that if a product is made up of bamboo it is more environmentally friendly.

But, only when you do an LCA you might better be able to quantitatively say that in a given context for the given system boundary, for the given scope reference system and

functional unit, whether bamboo as a material is a more environmentally friendly solution or plastic or ceramic and so on.

So, similarly in this qualitative evaluation because we are only doing qualitative evaluation it is very difficult to evaluate. Of course, you can bring in lots of stakeholders who have some degree of expertise in that particular field and when many of them evaluate your design, you can still say that because it has been evaluated by a team composed of lot of experts. So, there is a higher degree of evaluation being correct the chances is much higher but, a qualitative evaluation can never replace a quantitative evaluation.

Because, our qualitative evaluation does not give us a detailed view of the results, it does not tell us the impact environmental impact of each and every aspect in terms of say the carbon footprint or the eco burden and so on. Hence, it is very important to have some kind of quantitative evaluation as well. So, there comes the, life cycle assessment method.

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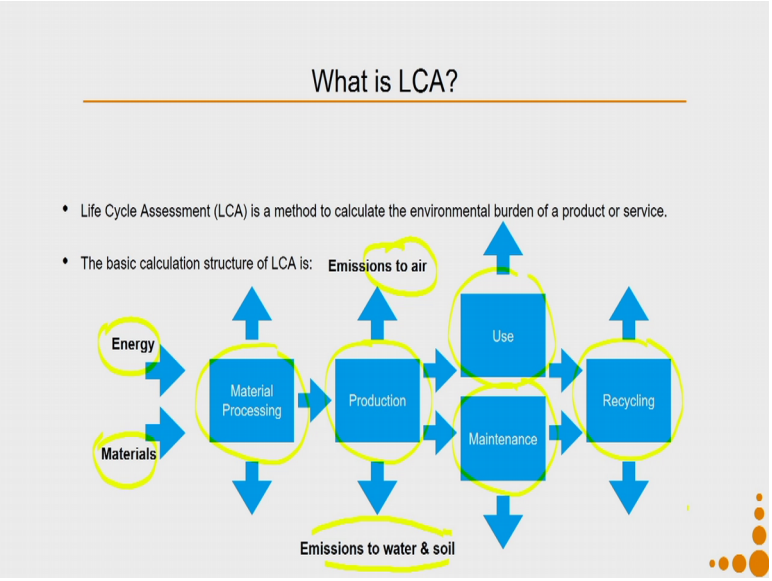

So, as we discuss the life cycle assessment method is a method to calculate the environmental burden of a product or a service. So, the basic calculation structure of a LCA it consists of so, you will have various processes. So, you have material processing, you have production then, the use phase, the maintenance and the recycling. And during each of these stages you will have certain kinds of inputs which are energy materials and

you will have certain, kind of emissions to water, air and soil. So, when we start computing these elements separately we will be able to calculate the environmental burden of a product or a service.

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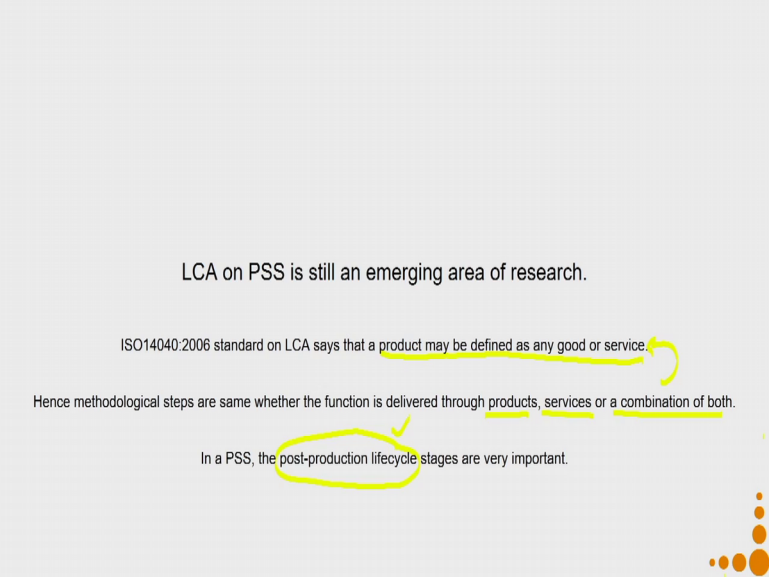

So, LCA on PSS is still an emerging area of research. So, all those people who are going through this particular lecture series and are very excited about doing research in this particular domain this is one very prospective research area how to conduct a in a LCA, on PSS. So, we will present the various viewpoints, the various challenges in this particular lecture to highlight these challenges. I will also present three case studies, I will present the research paper links to three case studies, of applying LCA on PSS all the three are meant for different kinds of contexts that even if, you go through all those papers you will get an idea of the width of the spectrum the various challenges and so on.

So, as we discussed during our LCA lectures, the ISO 14040 2006 standard it says that LCA can be done for a product and the product may be defined. So, you can define your product as any goods or service. So, as per this definition I should not be having much problem but unfortunately, not much research has been done on application of the LCA to services and now, we are talking about product plus services system together as a whole.

So, methodological steps are same whether the function delivered is through products services or combination of both. So, as for this particular definition of ISO 14040, the

methodological step should be same. But say for example, one point of difference which comes is as we were discussing when we were discussing about doing the LCA of a PSS, we could take a cradle to grave we can take a cradle to cradle, we could take cradle to gate, we could do many different kinds of analysis.

But, see in the context of PSS as we have already learned the post production lifecycle. So, in the use oriented or the result oriented PSS the post production life stages are very important because, the product is still owned by the company. So, the so clearly from this we know that already we cannot do a cradle to gate analysis it does not make any sense cradle to grave or a cradle to cradle analysis only makes much better sense. Also because in a PSS is the post-production lifecycle stages are very important there a lot of complexity is related to the systems mapping because, as soon as the product enters into the use phase, lot of uncertainties come which are not directly under the control of the providers.

Say for example, if I am supposed to use the washing service as soon as the service is put into the market and it enters the consumption phase there can be many uncertainties related to what happens thereafter in the use in a during the use phase. Say for example if, there is a community of washing machine and people start using that community washing machine but in the meanwhile, there are many such consumers who start complaining that what is going to happen about washing machines which we have at home.

We want this company to buy back all our Washing machines and compensate us accordingly [vocalized-nose] so, this is an unexpected scenario. There are many expected scenarios so, you always try to build them in the system as different scenario, but there can be completely unexpected scenarios which is even very difficult to imagine at the onset.

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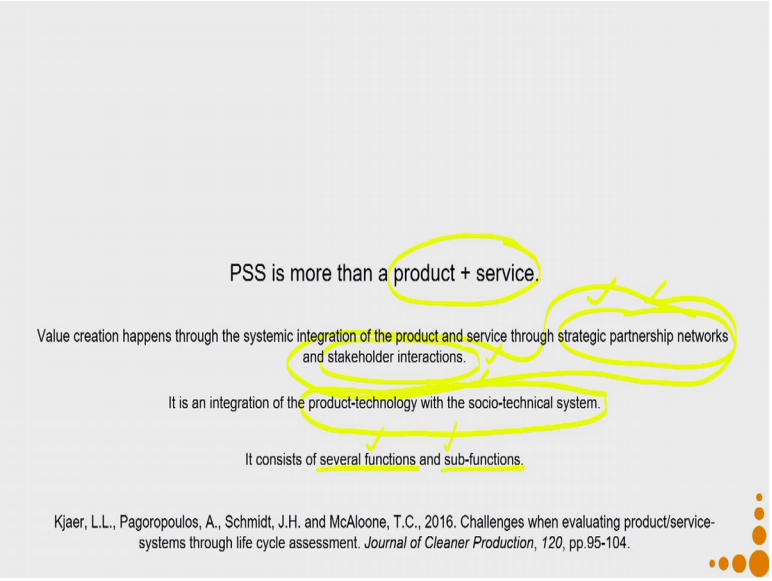

So, PSS is more than a product plus service that is where the whole challenge of applying LCA comes. So, in a PSS value creation happens through the systemic integration of the product and service through, strategic partnership, networks and stake holder interactions that is why, we are saying that PSS is more than a product plus service.

So, there are many strategic partner networks and stakeholder interactions. Say for example I want to offer a particular washing service; the washing service is going to come to your house. Now, a as per my PSS design imagine that the washing service uses the electricity connection from my home. What it offers me is per unit of a it offers me in the washing services is an I pay on the basis of say number of clothes that I wash or the weight of the clothes that I wash and so on there could be many parameters which would be said. But, it still uses the electricity connection from my house.

So, which means it is using the grid electricity; which also means that, it depends on the fact whether at the time when they came to my house to offer that particular service and the electricity connection should be up. There are so, times when in during the day time or during the night in our country when there is no power at home at our homes.

So, you can see that in this particular context in a PSS offering your offering is dependent not only on internal strategic partners that you have built. But, it also depends on all those support services whom you will be using or say for example, in order to

reach my PSS to your home I might be using the internet service or the mobile, network service.

So, I will be involving lot of strategic partners and lot of stakeholder interactions. So, the value creation is created with in a combined manner with all of these stakeholders together. So, it is in integration of the product technology with the socio technical system which is already in plays. It consists of several functions and sub functions as a result of the fag that it is a combination of products and services along with a interesting strategic partnership network, stakeholder interaction, product technology base, socio technical systems; I might be offering actually several functionalities and sub functionalities.

See again coming back to this example of washing clothes say in one part I design a particular PSS. So, my satisfaction unit remains same my satisfaction unit is I want clean clothes so, I can design many different types of PSS around it. Say for example, first PSS that I design is a service, which comes to your house and you can give the clothes and depending on your clothes, depending on your requirements, this person washes the clothes in your own house and gives you the clean clothes. This person might be using the electricity and the water connection of the house it itself and offering this particular service.

Now, what I am getting in this case my function one is of course clean clothes that is the most important function. Now if, I say about talk about the sub functionalities I am getting this service available to me at my doorstep. So, there is a sub functionality added over there that clean clothes at your doorstep but, I do not have to go anywhere.

Now, see this PSS could also have been designed in a manner that, this particular solution provider comes with the setup which has it is own electricity generation of the power generation source whatever, might be so, large it might be diesel generated power whatever. It also has it is own water supply and it also has it is the machines for cleaning the clothes. So, all I have to do is give the clothes and I get back clean clothes at my doorstep.

Again you can see that the functions and the sub functions are changing. Now, I could also have a wash bar as we saw the LG wash bar example. So, it is a local cafe where I can go take my clothes until my clothes are getting washed, I can enjoy the coffee shop. I

can also engage into social chatting with my friends always strangers I can also play some games over there.

Again the main functionality the Satisfaction unit remains same but, it has add on advantages it will other functionalities like a social setting it also offers you coffee and it can also be a place for entertainment. So, now sub functionalities are changing so, I had the same satisfaction unit, but I can offer different PSS around it.

Each one can be a sustainable PSS but, since each one of them are different in terms of their functions and sub functionalities. If, you recall the functional unit or the concept of declared unit from in the LCA lectures, you will find that that is the major challenge in this in applying LCA to PSS because, the functions and the sub functionalities can change and it might become very difficult to set a equivalence value for each of them.

So, you can go through this particular paper challenges when evaluating product service systems through life cycle assessment, this paper in detail lists out all these different challenges they also, have references to many other papers where people have tried to apply LCA to product service systems under different contexts and they have followed different strategies to do the same.

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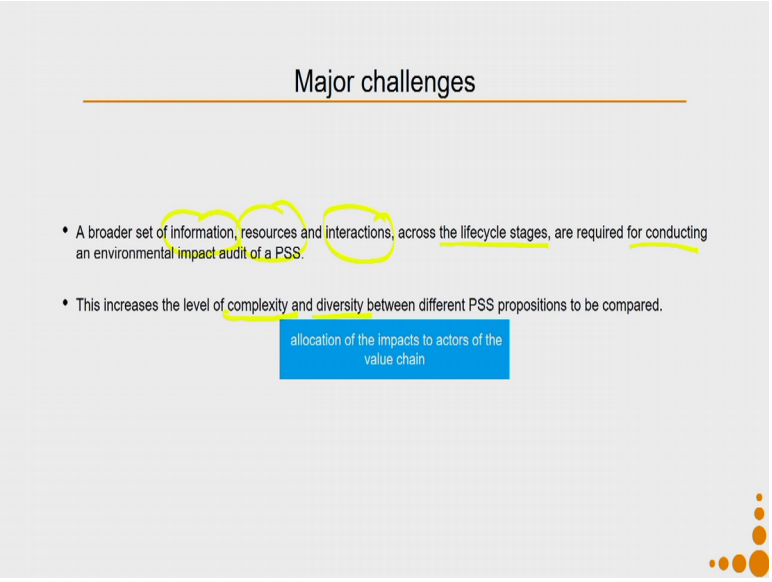

So, some of the major challenges that we face when we are trying to apply LCA to PSS are, in the context of PSS because, it is combination of product services along with

strategic partnerships between various stakeholders. We have many foreground systems and background systems, foreground systems the providers have control over them it is located within the providers and the background systems are those which are outside the control system of the providers.

So, say like the road network the infrastructure network the administrative aspects and so on. So, because the system boundary becomes very big so, the amount of information required to do the analysis is very high, the resources required is very high and we have to consider the num last number of interactions across the life stages. We also cannot ignore any of the life stages we cannot do for the sake of simplicity say cradle to gate. We have to, take into account the entire life cycle otherwise so, the benefit of a PSS comes only through the entire life cycle.

So, all these are required for conducting the environmental impact audit of a PSS. So, this increases the level of complexity that we have to deal with and also the diversity. So, the complexity also increases in another aspect which is allocation of the impact to actors of the value change. So, if you remember from the LCA lectures, that we went through allocation of the impacts to actors was way much more easier. Here in this case because of the network of actors built in allocation of the impact also becomes more difficult and that in the case of product.

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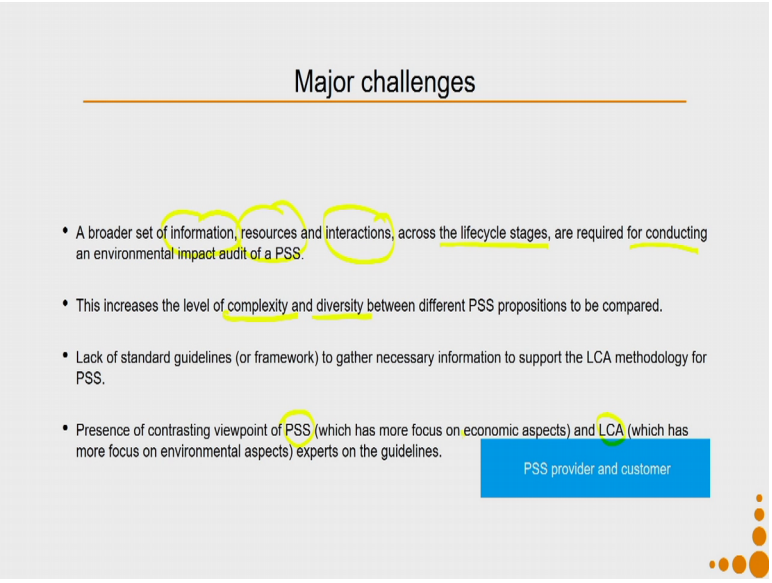

There is also lack of any standard guidelines or frameworks to gather necessary information to support the LCA methodology for PSS at this given in a moment. So, that becomes an interest area interesting area where for the research can be conducted. Presence of contrasting viewpoints of PSS, which has more focus on economic aspects and LCA which has more focus on environmental aspects is also there. So, PSS experts and LCA experts, they have certain contrasting viewpoints also on how to perform this evaluation this environmental evaluation.

So, why I am talking about the economic aspect in PSS? So, if you remember the definition of PSS that we said it was like an offer model in which it is in the economic interest of the providers to be economically and socially sustainable. Also for the consumers because PSS always demands certain kind of behavior change in terms of, consumption so, for the consumers also the economic aspect becomes very important. They might not want to go ahead with the PSS in the in cases, where the initial investment or the recurring investments are very much higher than that in the ownership based model.

So, in amongst the PSS experts a major focus lies on the economic aspects both from the provider as well as the customer, perspective; whereas, in the LCA, amongst LCA experts the focus on the environmental aspects are very much higher.

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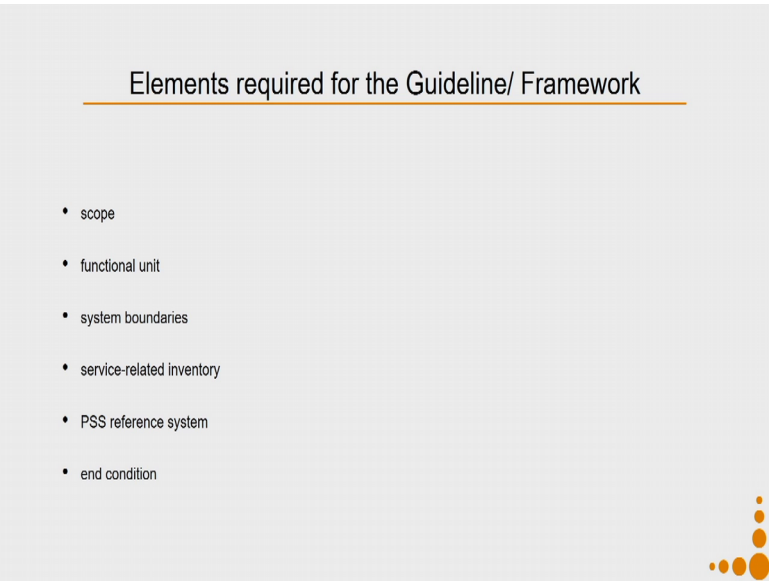

So, let us, discuss the elements that are required for this guidelines of framework conducting LCA on a PSS. So, these are the same elements that we discussed when we are discussing our how to in a conduct life cycle assessment. So, we have to have scope, we have to define the functional unit, the system boundaries, service related inventory, PSS reference system and the end conditions. So, let us pick up each of these elements and see how they are done and the challenges that we face.

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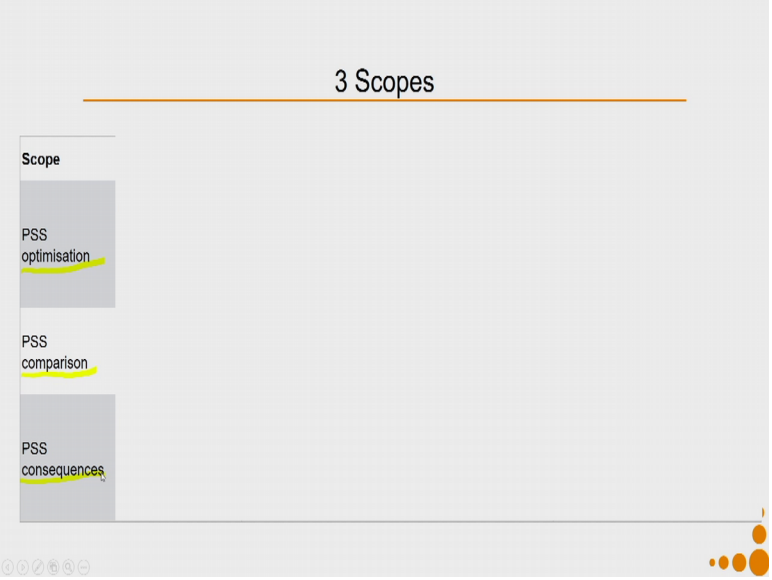

So, there are 3 kind of scopes, when we try to do an LCA of a PSS. The first one is called as a PSS optimization, second one is PSS comparison and the third one is PSS consequences.

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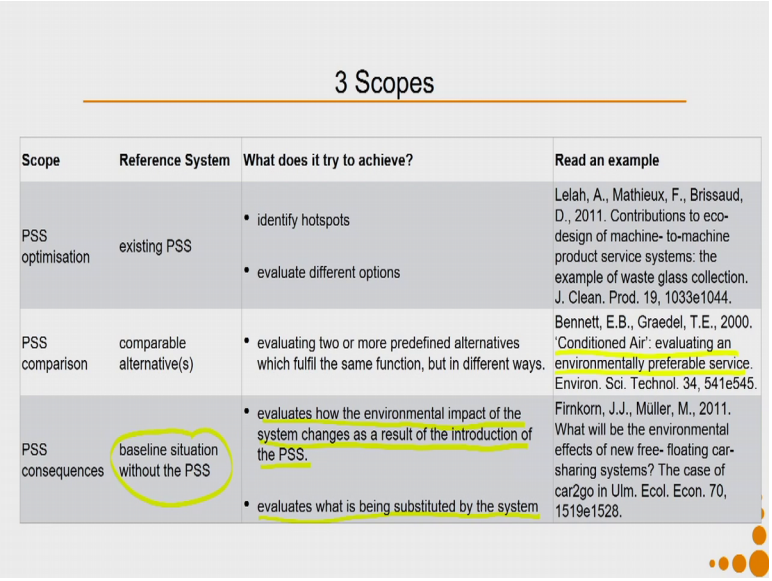

So, what happens in PSS optimization? In this particular context we take one PSS and we try to in that same PSS we try to identify, where are the different hotspots, where are the major environmental issues and we try to evaluate different options. This is the easiest context why because, in this case the system boundary remains constant, the functional unit remains constant, the sub functionalities remain constant. What we try to do is optimize this particular PSS by identifying the hotspots and evaluating different options.

If you are interested in seeing an example of applying this kind of applying LCA to this kind of a PSS, where you are trying to do optimization you can read this paper it talks about contribution to eco design of machine to machine product service system with the example of a waste glass collection.

Next one the PSS comparison; here I am trying to compare alternatives, as soon as I try to compare alternative PSS. So, these can be comparison with respect to alternate PSS possible or also with respect to a traditional way of doing business that is product oriented business. So, what I have to do over here is I will be evaluating two or more predefined alternatives which fulfill the same function, but in different ways.

A major challenge over here comes on the same function because, defining the same function as I gave you the example of the clean clothes service it is very difficult, setting of this equivalence is very difficult. Again in this case also if you want to know more

about this particular technique so, there has been an evaluation between conditioned air and air conditioner. So, air conditioner is the product model and conditioned air is the service model and this paper presents to you a particular technique of doing else here, in which you compare a product offering versus PSS offering.

The third one is the PSS consequences; in this case you have are talking about a baseline situation without the PSS. So, what it tries to do is evaluates how the environmental impact of the sensitive system changes as a result of the introduction of the PSS. As soon as you read this statement you can see that, it is a very predictive model because, the changes can happen in many different direction and the degree of change to each of them can also vary, it also evaluates what is being substituted by the system.

Say for example, if I bring in a car sharing system what all it can in have been impact on? It might have an impact on the metros, it might have an impact on the trains, it might have an impact on intercity travel, it might have an impact on travel by walking, it might also have an impact on travelling by bicycle. So, in this PSS consequence we are trying to evaluate the environmental impact of the system changes as a result of the introduction of the PSS; which is all only a probabilistic way of looking at it because I do not know, what all systems it will substitute and to what degree it will substitute.

Another aspect which comes over here very importantly is the rebound effect. Say for example now, I do not have to own car because, I can take this car sharing service. So, from travelling point a to point b, which I would have otherwise gone by my bicycle or I would have walked I might decide ok, the cost of getting us in a shared or a rental car is very low at this, location or in my city, why should I care to walk or why should I care to use my bicycle let me take a shared car.

Now, say if you are you have to travel to the local train station and the local train station is only two kilometers away earlier you would have taken a public transportation like bus, now you are going to take this shared cab service. So, at the train station this might increase a lot of congestion due to cause. Also because rather than using buses which are mass transportation services I am going to use cars which will take a lesser number of people or only it say just me from point a to point b. So, what I am getting over here is a environmental rebound effect.

Traffic condition as well as maybe increased ecological footprint because, rather than using a bus or rather than walking I am going to use this cab service. So, in these PSS consequence measurement if the scope of it is that it is very difficult to even imagine all the possible rebound effects because, they will depend on how people consume how people change their needs once this particular new PSS is introduced. So, you can go through this particular people what will be the environmental effects of new free floating car sharing systems. It discusses the same context it also discusses a possible way of doing a life cycle assessment when you are trying to when your scope of work is PSS consequences.

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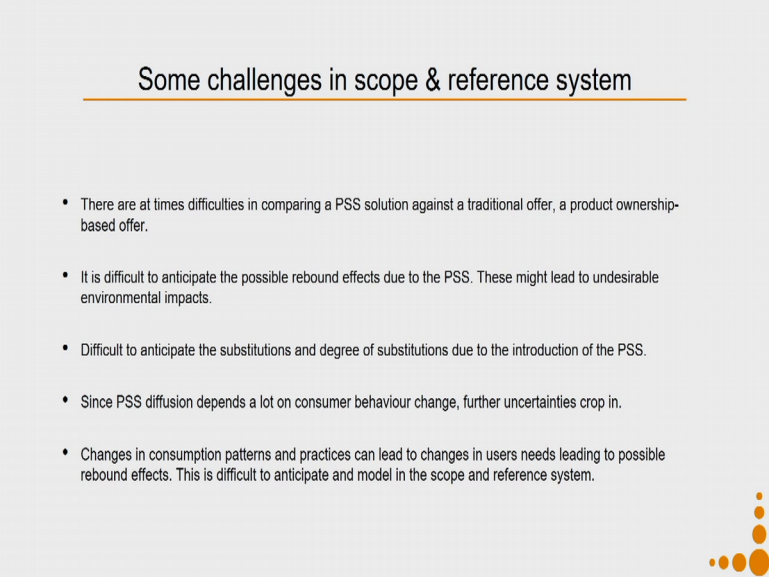

So, some of the challenges scope and reference systems is so, there are, at times difficulties in comparing of PSS solution against a traditional offer a product ownership based offer. Say for example, if I want to compare a washing machine versus a clean cloth offering service. Because of the size of the system, because of the all the usage related, maintenance related uncertainties and scenarios it becomes very difficult to compare them. It is not that it is impossible to compare it but, the comparisons are always like on the basis of scenarios of usage and you might have to compare many scenarios of usage and in actual practice the actual scenario might be very different that is a possibility.

It is difficult to anticipate the possible rebound effects due to the PSS. The say for example, I gave you a very imaginary rebound effect due to the washing machine or due to the car sharing service. When you are doing this LCA of the PSS you try to think of as many possible rebound effects as you can but, not necessarily you can predict the exact rebound effect.

These might lead to undesirable environmental impacts also, at many times. It is also difficult to anticipate also be aware that even when you are doing an LCA of a product because, you cannot really ensure what happens to the product when it reaches the users end you do not have really a good control over the end of life also in that particular case. Those calculations are also scenario based.

But, the number of possibilities in the context of PSS increases exponentially as compared to that in the case of a product. The next challenges is it is difficult to anticipate the substitutions and degree of substitutions due to the introduction of the PSS. So, how many people will substitute, their current washing machine into a better solution or if, they are going to do that are they going to discard away their washing machines are they going to send it to a scrap dealer are they going to sell it in a second hand market or they are going to keep it in their house to use in case the service they could not access the service on certain day and time because of any other reason.

If, you have a car sharing service it is difficult to anticipate to what degree it will substitute the current public transportation or the desire to own your own vehicle. And those aspects need to be mapped when you are doing the scope and the reference system and your LCA calculations depends on them in a big way. So, you are always considering scenarios ok, if 10 percent of substitution happens 20 percent of substitution happens.

Since, PSS diffusion depends a lot on consumer behavior change further uncertainties crop in. Changes in consumption patterns and practices can lead to changes in users needs leading to possible rebound effects we also discussed about that. So, this is difficult to anticipate and model in the scope and the reference system. You will always model some of them but you can never be sure, you can never claim that these are the only possible rebound effects.

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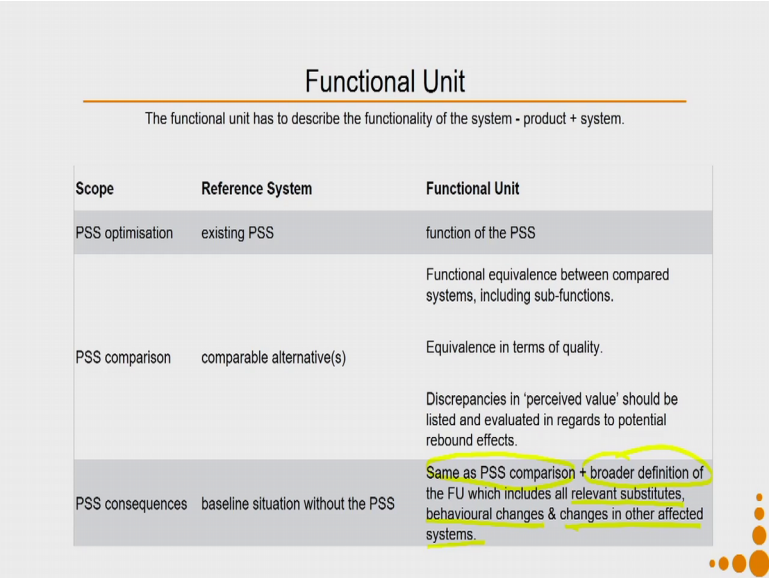

The next element is the functional unit; so, the functional, unit in case of a product it used to be the functionality of the product. So, we had defined the functionality of a coffee machine as per cup of coffee for the case of five cups of coffee our day where the coffee pots are coming from Thailand to India.

So, that was how we define the functional unit in the context of a products life cycle assessment. In the context of the PSS the functionality of the system has to be that of the product plus the system as a result, all the problems because, it is very difficult to associate one functionality to it. So, whenever I have this first scope which is the PSS optimization of a existing PSS design, what we are trying to do is the functional unit in that case is the function of the PSS. This is still a more easy to handle context because, the functionality of the whole system because you are doing only, identifying the hotspots and doing the design changes at the hotspots.

So, the function of the PSS and the sub functionalities are most likely going to remain more or less same or that is setting the equivalence value is very much easier as compared to the PSS comparison and PSS consequence. In PSS comparison where are we are trying to compare alternatives first what I have to do is, functional equivalence between compared systems including the main functions as well as the sub functions. So, like all the different ways in which I can offer the Satisfaction Unit of clean clothes that we discuss, they all have different functions.

So, the wash bar has a different set of functions plus of functionalities; the washing service which comes to your home and delivers you the service or say washing machine owned by the entire building; they offer you the same satisfaction unit but, the main functions and the sub functionalities are different. So, I have to try to establish some kind of functional equivalence both between the functions and the sub functions in case it is not possible then, we cannot compare to PSS for doing an LCA.

This does not imply that you will not design PSS with different kinds of functional and sub functional options just because you wanted to do an life cycle assessment. Today's lecture is purely from the perspective what are the life cycle assessment difficulties? This does not imply that you design the PSS in a manner that you can do LCA that is not the aim. Then we have to also establish equivalence in terms of quality which is the perceived value. As a consumer, I will see a different value to the wash bar, as compared to a service in which there is a door step washing service as compared to the self help or do it yourself service which is available in your building basement.

So, where nobody is offering you now, person is doing it for you go put your clothes at for your convenience and availability of the washing machine and get clean clothes. So, the quality and the perceived value in each of these PSS design is different. So, again there is a problem if, that is the case we cannot do a comparison of LCA between all these PSS because the functional unit is different.

Hence, to do it in case when we want to do it, we have to see that there is sufficient amount of equivalence in terms of quality discrepancies in perceived value should be listed and evaluated in regards to potential rebound effects. The last one is the PSS consequences; so, it has things which are same as the PSS comparison plus here you have to have a broader definition of the functional unit which includes all relevant substitutes behavioral changes and changes in other affected systems.

So, is the setting up of the functional unit is the most difficult my task in the context of PSS. Some researchers suggest that rather than trying to set a functional unit like, you remember we set a declared unit also in case of certain products. Say like jewelry, shoes, clothes where functional unit does not make much sense because, they are bought on the basis of the positive value offered by these particular products, we had this concept of declared unit.

Similarly, some researchers argue that the context of PSS also we rather than having functional unit, we can compare PSS on the basis of this satisfaction unit or the positive value. But, even when you say that even implementing a that is very difficult because again the sub satisfactions in the example of the wash bar are so very different. So, they will have different values but still because, we are comparing on the basis of eco- cost or value model.

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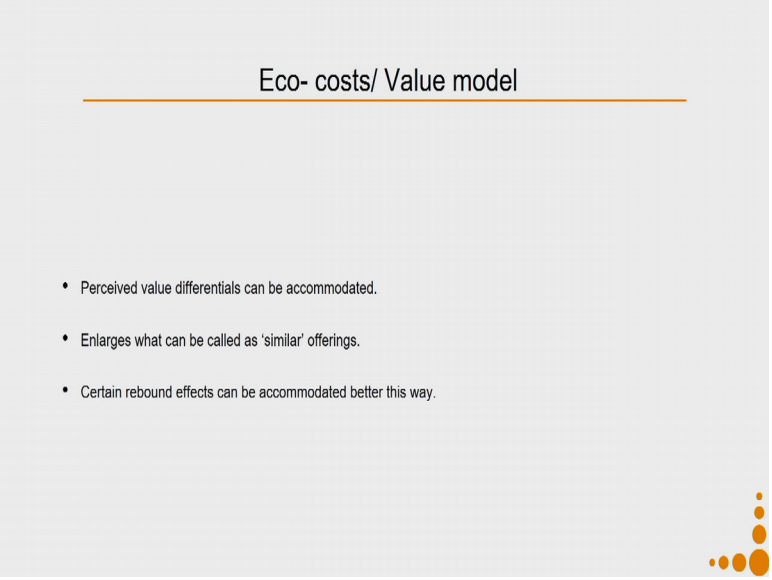

So, satisfaction unit or the value base model they will follow the eco- cost or value model. So, we will be in a better of situation than just the functional unit. So, let us, discuss some of the challenges in describing the functional unit.

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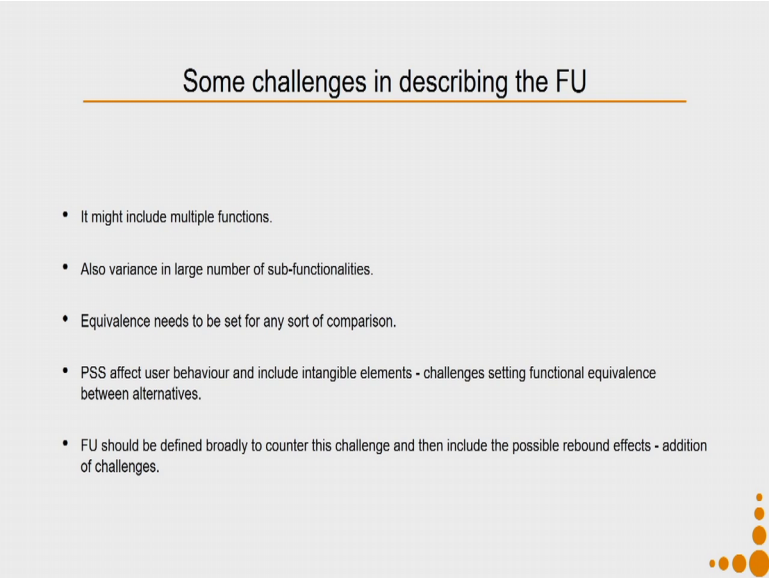

So, as we already discussed it might include multiple functions, where as in LCA the definition of LCA goes by single functional unit so, there is a methodological clash. There is also variance in large number of sub functionalities even if, you ensure that the even if, you ensure equivalence at the functional level at the sub functionality level when you are trying to compare alternative PSS or you are trying to do PSS consequence, the sub functionalities level the setting the equivalence is very difficult way much higher variance is available.

Equivalence needs to be set for any sort of comparison, PSS effect, user behavior and include intangible elements these are the challenges in setting functional equivalence between alternatives. So, I will see different things in a different services although different what services I see them in a different manner.

Functional units should be defined, broadly to counter this challenge and then include possible rebound effects which is another additional challenge while we are trying to do a life cycle assessment. Because, each of these sub functionalities so, the home delivery, clean clothes has very different sort of rebound effect possibilities as compared to the wash bar as compared to the building level washing service.

So, the eco-cost of value model can be an alternative way. Here what you are trying to do is, you take the perceived value differentials and you can compare the PSS it also enlarges what we mean by similar offerings. So, it also helps in setting the perceived

value in terms of similar offerings. Certain rebound effects can be accommodate in a better manner when we look using this particular model.

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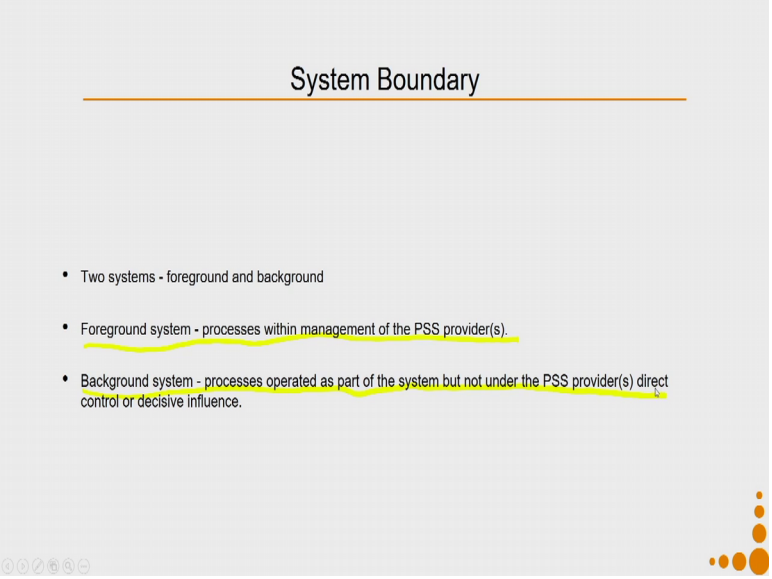

Now the third and the last element; the system boundary so, for PSS, the system boundary consists of two systems, the foreground and the background system. So, the foreground system, it consists of all the processes within management of the PSS provider. So, in case of this wash bar so, the company who is say the washing machine company owns the washing machine; they also setup the washing bar. So, the space is also owned by them, they might be offering the games and the drinks which are provided by yet another manufacturer.

So, we will define a certain set of providers in this case, this in this particular functionality see the electricity is provided by somebody on whom the provider does not have much control. Then, I put this particular provider as a background system how does this have an effect. Say for example, you locate this wash bar in a place where there are frequent power cuts your wash bar has to work irrespective of the fact whether the municipality at that point of time is giving in power to the locality or not.

So, in that context my provider might have to also set up a small power generation unit in their premises which ensure that the washing machine is working all the time. So, in this background system because the PSS provider did not have much control or decisive influence on the say the power company or the municipality who through whom the

power my is coming to your setup. So, I had to do certain changes into my foreground system I had to build in this particular generating electricity generating unit in house.

So, when we are talking about the system boundary in the context of PSS we will talk about the foreground system, which are processes within the management of the PSS provider and we will be talking about background systems, which are operated as part of the system but not under the PSS providers direct control or decisive influence. This might include all sorts of infrastructure say roads, electricity, educational setups and so on. It might also include things like administrative services, law and order depending on what your PSS is about. So, let us again go to each of those scope definition and see how the system boundary definition changes.

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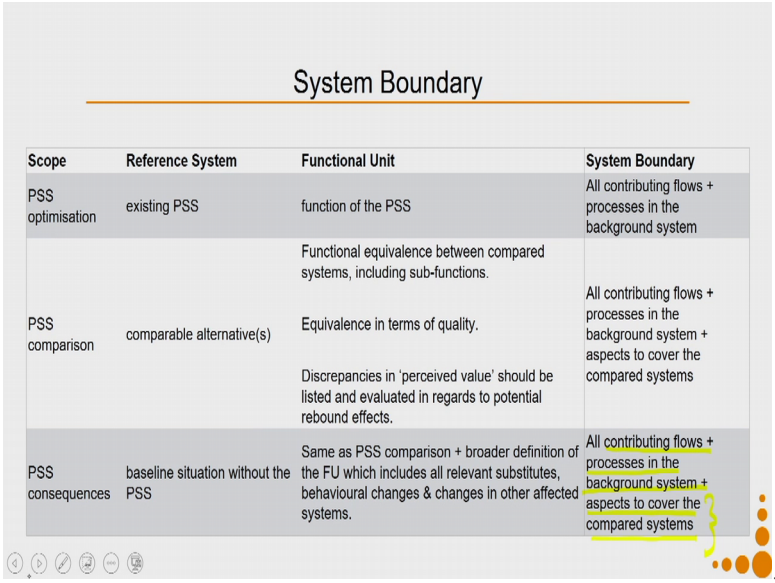

So, when we are talking about PSS optimization that is the within the existing PSS. In this particular case the system boundary is all contributing flows, plus processes in the background in a system so, all the foreground plus the background system. Let us, go to the next one PSS comparison so, again I have all the foreground or the background system plus the aspects to cover the compared systems because, as soon as I try to compare two systems there will be differences in the stakeholders there will be little differences say in the boundary conditions from for both the contexts.

So, I have to bring in aspects a in both the system boundaries so, that I can compare the both the systems. Similarly, when I am talking about the PSS consequences I have

something similar like the PSS comparison I will have the foreground flows, the background flows and the aspects come cover the compared systems. So, when I start doing all the foreground plus the background plus aspects to cover the compared systems that adds on lot of complexities.

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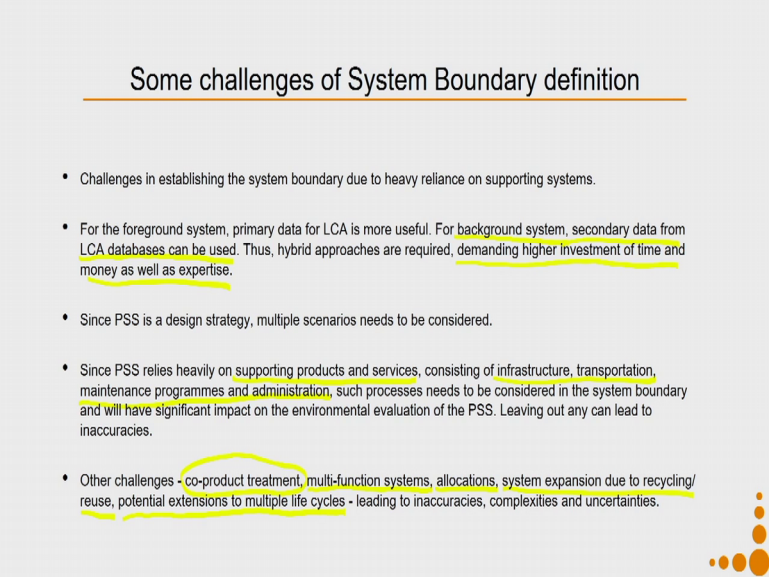

So, let us discuss, some challenges of system boundary definition. So, challenges in establishing the system boundary due to heavy reliance on supporting systems. So, I have a huge reliance on the background systems because, it is like product plus service and I have to rely on all these background services which are going to help me in being able to deliver my PSS.

So, setting the system boundary becomes very difficult like where do I say that this is my boundary. Should I include the real network, should I include the nuclear power plants in the country, should I also consider the say the electro city grid of two countries are connected should I consider this whole system as a whole. So, setting the system boundary is little difficult in this particular context.

For the foreground system, primary data for LCA is more useful if, you remember when we were doing the LCA analysis of the product we did quick LCA in which, context we were using data from the databases.

So, whenever you are using the background system which is like the existing infrastructure or administration it is to use the secondary data from LCA databases. But, for the primary data which is like the all the processes which are maintained by the providers. You might have to actually go for primary data which means, you will have to involve some kind of LCA expert who can calculate the impacts for the given set of design that you have done.

So, hybrid approach is most likely required thus, you might need higher investment of time money as well as expertise in this context. Also since, PSS is design strategy multiple scenarios needs to be considered. So, in case of the product LCA we considered couple of scenarios say, in the case when the coffee pots are coming from Thailand to India, in the case when the coffee machine is made in China and shipped to India.

But, in the context of PSS you can just in because there are so many components you can come up with multiple scenarios. So, the number of scenarios to be considered in the system boundary is very large. Since PSS relies heavily on supporting products and services so, these supporting products and services are the background a system consisting of infrastructure, transportation, maintenance programs, administration and so on. These needs to be considered in the system boundary and will have significant impact on the environmental evaluation of the PSS.

So, in case you miss on to any of them, it can lead to in accuracies. So, mapping all of them is a challenge and in case you miss them, you can get in lot of inaccuracies which can give you a false feeling that the service model is more environmentally friendly; which might not be case because to even to produce a service you need products and infrastructure which have high environmental impact.

There are many other challenges so, say for example; like in the LCA for products we had away of doing system expansion when we have a byproduct. So, in this particular case also in PSS also you might get something called as the co-product or the byproduct. So, in case of a product we called it byproduct here we call it as co-product it becomes more challenging to accumulate the co-product in because already system boundary is extremely complex.

Also, your system might be multifunctional system, how do we do different allocations to different actors is a big problem system expansion due to recycling and reuse they

actually, give the PSS it is sustainable sustainability orientation in a big way. But, doing the system expansion due to recycling or reuse and doing the calculation with respect to that is extremely complex and it is usually, advice not to do that and then, your whole point whole sustainability crux is lost to a big extent.

Similarly, potential extensions to multiple life cycles that is what PSS offers but, computing that were representing that in the system boundary is very difficult. So, all these things lead to unique accuracies increase and complexities, as well as uncertainties. So, the all because of these aspects it gives us a huge scope for doing research in this area and coming up with appropriate ways of doing LCA.

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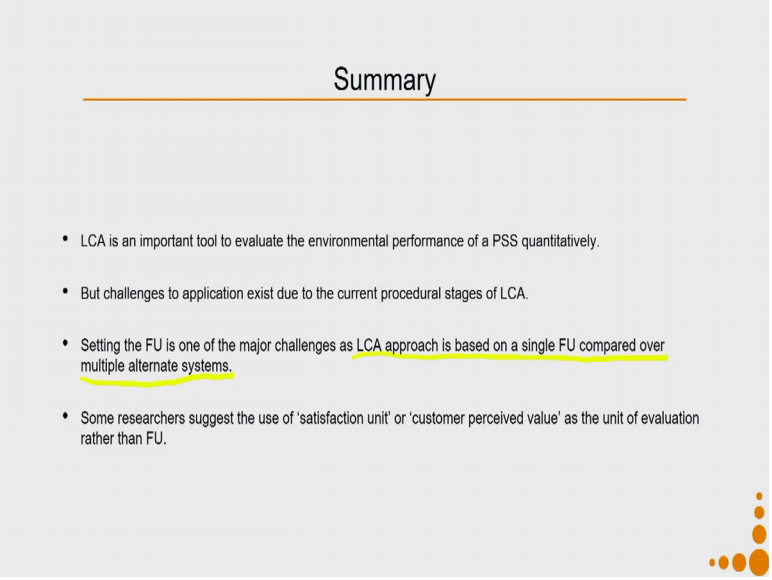

So, to summarize this particular lecture, what we can see is, LCA is an important tool to evaluate the environmental performance of a PSS quantitatively and it is very important to do the same. But, as we discuss the challenges to application exists due to the current procedural stages of life cycle assessment because, the procedural stages of life cycle assessments means, may develop keeping in mind a product. It did not it was not designed thinking in mine product plus services along with all the interactions between different stakeholders.

So, a that is why I also another challenge which came up the setting the functional unit of a LCA. So, in the LCA approach setting the functional unit is based on a single functional unit, compared over multiple alternate systems which is not the case with the

PSS. Hence the scope for appropriate equivalent of desired defining a function unit can be worked out.

So, some researchers suggest the use of satisfaction unit or customer perceived value as the unit of evaluation rather than functional unit. So, hope you had a good understanding of what are the challenges of implementing LCA on a PSS and why it also gives you an idea why not much work has been done in that domain, but more and more PSS evaluation on it is sustainability performance has been done qualitatively. A qualitative, tool is a good tool and can be used, but to get actual numbers on the environmental parameters better LCA approach can be developed.

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So, in our next lectures, we will in our next week, we will start discussing about other design for sustainability tools and approaches which will be coming from the field of distributed economy, architecture, agriculture, cities and communities and about carbon footprint

Thank you so much.