Advanced Topics in Science and Technology of Concrete
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Recycled concrete aggregates market: problems and prospects - Part 2

And that takes us to the concept of why we recycle or why should we recycle. So there is a popular misconception that recycling should be carried out because to reduce waste. And when they say they need to reduce waste, they usually mean to reduce landfilling. But is that the real reason why we recycle waste? Quote the kind of values or the impact or the carbon footprint for each of these operations. For landfilling in a gate-to-gate system boundary, it is about 4 kg CO_2 equivalents per tonne. That is the kind of impact that landfilling generates.

On the other hand, recycling every tonne actually kind of generates an impact of 5.5 kg CO_2 equivalents. Which means recycling actually impacts more than landfilling. Which is actually countering our earlier argument that we are recycling because to reduce waste or landfilling. Of course, these numbers are actually highly dependent on the transportation impacts. But taking a gate-to-gate boundary, so this is the number. So then why do we really recycle? We really recycle because it displaces primary production. See for instance, for pristine aggregates, production of every tonne actually generates an impact of 12.5 kg of CO_2 equivalents. On the other hand, recycling only generates about 5.5 kg CO_2 equivalents for every tonne being recycled. So therefore, net-to-net, the savings is actually about 7 kg CO_2 equivalents per tonne, if we pursue recycling. So that is the predominant benefit that we get from recycling. But the caveat here is, it basically has to displace the pristine aggregates production for every tonne of recycling.

So, what are the broad benefits of recycling? So, the first point is the avoided impacts of primary production, which is very clear. So, in our case, we kind of eliminate 12.5 kg CO_2 equivalents per tonne of carbon footprint by recycling. Because we will actually recycle the waste generator, we will also avoid the impacts of landfilling because it becomes a pair. Like whatever we are going to put in recycling, we are not going to put it in the landfills and therefore we will also save the impacts associated with landfilling.

And whatever the impacts of recycling operations are such, so for instance, the 5.5 kg that has to be deducted. So, this is the equation to find out benefits of recycling. But this is actually a theoretical equation and represents a highly ideal case. Why do I say that this is a highly ideal case? Because whenever this is an engineering point of view of how the system operates, for instance, in the linear economy, so the primary production happens.

Then in the use phase or operations phase, for instance, in construction or constructed facilities, the materials say pristine aggregates are being used. And after demolition, it kind of entered landfill earlier. But right now, we are trying to collect the waste and recycle and kind of circulate it back to constructed facilities or construction activities again. So, therefore, we kind of assume that this is kind of creating a circular economy instead of a linear economy earlier. There is a significant assumption here that we are missing.

What is that? Is for instance, for every one ton of C&D waste that we collect, there is nobody who sits at a quarry and says, hey, let us quarry one ton less because we have actually collected one ton of C&D waste in our recycling facility. Does it happen? No. So, our assumption of taking the recycled products and again using it back and eliminating the primary aggregate looks slightly unreliable now, is it not? Why? Because our system in an engineering point of view, what we missed out is the materials market and its mediating role between production and consumption. For instance, the primary products come into the materials market and the recycled products also come into the materials market. And therefore, there is a competition between the primary products and the secondary products, which happens in the materials market and the use phase kind of gets its material from the materials market.

And therefore market plays a crucial role in the economic system and this is where assumption of displacing primary production kind of gets questioned. For example, let us take that there are two products which are substitutes. In our case, pristine aggregates and recycled aggregates. Supply of an increased supply of one or an incentive for one of it will actually result in reduced prices for both products. How am I saying this? For instance, let us assume we have a system where there is a constant production of natural aggregates or pristine aggregates.

Now, suddenly we are recycling say X quantity of waste and producing X quantity of recycled aggregates and bringing the recycled aggregates to the same market where even primary products are being sold. So, what happens in the overall market is earlier there was a quantity of X and now another quantity of X has joined the market and therefore there is an increased supply of products. Whenever there is a higher amount of supply, what happens is price kind of drops and therefore this happens with recycled aggregates. Let us assume because for various reasons in terms of the barriers associated with cognitive aspects, the unfavourable attitudes, recycled aggregates or in terms of the incentive that the government gives for recycling, let us assume that the recycled aggregates prices are less. What happens is then people will start consuming recycled aggregates as compared to natural aggregates because there is a price advantage.

Now, looking at this, the primary production counterparts will want to also sell their products and therefore they will start reducing their prices so that they can compete with the recycled aggregates. So, this kind of becomes a cascading issue where both products will finally get reduced prices and because of the reduction in prices, the consumption of these products will again go up. Because anyway it is now cheaper and therefore consumers will always buy things when it is cheaper. So, we have seen there is an inverse relationship between the quantity demand and the prices. So, once the price goes down, the quantity demanded or consumed goes higher and the overall consumption will always be higher than before.

Why? Because increasing supply of one good does not necessarily reduce the consumption of the another good by the same amount because each product has its own dynamics and consumers react to price changes in different ways. So, therefore consumers respond to price changes and the market size is actually not fixed. It is not a very zero-sum game where we have an extended supply of extraction being happening and therefore the market size keeps growing and growing and consumption increases because of the reduced prices for both of the products. That is not all because the competition can again shift to other markets too because of this phenomenon. For instance, while we assume that recycled aggregates are actually competing with pristine aggregates, in the real materials market that may not be the case and recycled aggregates might start competing with other alternative aggregates such as flash aggregates or crusher dust or any other products which are slightly less harmful as compared to the pristine aggregates.

And remember, the impact for recycled aggregates is somewhere about 5.5 kg CO2 equivalents per ton. And what is the impact for something like crusher dust which is prominently used as a filling option in most of the products. Therefore, right now the real benefit that we were earlier looking at in terms of difference between recycling which is 5.5 kg and pristine aggregates which is about 12.5 kg has suddenly dropped down to the competition between a crusher dust which is again somewhere close to again 4 or 5 kg and recycling which is again 5.5 kg. So, the benefits that we were envisaging earlier are not so clear or apparent right now. Why this happens? Because of the price effect that is induced by the market forces and the competition that happens in the materials market. So, we can safely conjecture that there is an inefficient displacement that could actually lead to rebound effects or unintended consequences at different economic levels.

This can happen at a particular market with respect to recycled aggregates and pristine aggregates or it can happen in the overall market with respect to several other alternatives such as fresh aggregates or crusher dust. Or it can also kind of start entering into competition in completely different markets and influence the resource allocation at a macro or even a global level as well. So, now we have talked about there is a competition that happens in the material markets and therefore we would want to know what is the percentage of primary production that gets displaced by the secondary production. So, let us take the recycled quantity as R and the change in the primary production as P. So, we can define the displacement rate as D as the relative change in the primary production divided by the relative change in the secondary production which is recycling.

So, the relative change in here with respect to the relative change in here is the kind of displacement rate that we are talking. So, therefore what we ideally have to do is while we initially thought that the benefits of recycling is avoided primary plus avoided landfill minus recycling impacts, the displacement rate kind of gets multiplied with the avoided benefits of primary production and avoided benefits of landfilling because that is the real quantity that gets displaced because of the secondary production or recycling that is happening. So, this if at all we want to identify what is the minimum quantity to which the primary production has to be negated because of the secondary production, we can equate that equation to 0 and find out the displacement rate for breakeven which is the ratio between the recycling impacts and the avoided primary and avoided landfill. We will have to note that this equation is significantly dependent on a particular impact category for a particular material for a

particular system boundary as well. So, this keeps changing whenever the impact indicator as well itself is changed.

If I take the carbon footprint which the data for which I have just shown earlier, the breakeven displacement rate for recycle aggregates is basically comes out around 33%. What it really means is for every 1 ton of recycling that we system, it has to displace at least 33% of the equivalent quantity of pristine aggregates production which means if the pristine aggregates production was 100 tons earlier and now the recycled aggregate is produced about for say 100 times 10 times, then your corresponding 33% increase or decrease in your pristine aggregates production must happen so that we do not increase the overall impact on the environment. And if the displacement or the actual displacement, an actual displacement can actually vary from 0 to 100. So, it can be either a 0% displacement which means a relative as in recycling quantity does not produce any difference in the quantity of primary production which means there is a 0% displacement. 100% is the whatever the result aggregates production happens, same quantity of pristine aggregates production has been prevented from happening.

So, that is a 100% displacement and in actual displacement, it can vary between 0 to 100 and what is the actual at any point of time the displacement will actually depend on the behavior of market participants. So, whether they are using recycled aggregates or not, that will actually define the actual displacement rate. So, can we trust our behavior to help us result in primary production displacement? The study in behavioural economics says no. For instance, the study by Todel and San using a different set of choice experiments with people has shown that whenever there is a recycling option being given to people in addition to trashing, what happened is the people kind of used more resources. For instance, in different experiments where the recycling option was actually present in addition to trashing for the people, the people were shown to be consuming 28% more cups, 19% more wrapping paper for activities, 43% more scratch paper as well as 32% more pens to kind of carry out the same activities that has to be performed as compared to the group that did not have recycling as an option which means the other group whatever the resources that they are consuming, they have to only trash it or dispose it.

But that is not just the only problem. The problem was once the people in both the groups were actually interviewed later the experiments, the people from the recycling option group,

they kind of felt better about their practices that they have adopted on an average as compared to the groups that had only the option of trashing. So what does this convey is while trashing has some amount of negative emotions in terms of guilt because we are throwing away this material or we have wasted this material. On the other hand, when people are getting an option of recycling, so recycling kind of gives a positive emotion or sometimes of happiness or proud feeling that we get because we are actually contributing to recycling something in the environment.

So that actually overpowers the negative emotions associated with trashing and in this particular experiment this has actually overpowered the emotions that are associated with the consumption of resources. So the real focus should have been in optimizing the resource consumption but people kind of started utilizing more resources when they know that the resources that they are consuming will be recycled eventually. That is the kind of message that campaigns in terms of recycling and circular economy have done is to actually project trashing as bad and recycling and other aspects as good. While in general all the aspects or all the options were actually bad, so therefore the options should have been campaigned as bad, very bad, very very bad. On the other hand, because there is a good marketing with respect to recycling and other similar R strategies, people have shifted away from optimizing their primary resource consumption to kind of start using more resources because they believe that it will anyway be recycled.

This is actually deeply problematic because as per the thermodynamic laws, whatever the material that we are going to utilize in the first cycle, the same amount of quantity will not be usable in the second cycle. Even in highly recycling systems such as in metals, we really don't see it and therefore the kind of extraction or primary material extraction that is going to happen because of the increased consumption of resources is the bigger concern that is actually standing before us. So the implications of this study is the recycling is beneficial only if the harmful primary production is prevented. For instance, let's take the concrete specification. For a non-structural concrete, we usually specify somewhere at M10, M5 and so on.

For a residential slab and so on, we usually kind of see the specifications as M25 or M30 grade of concrete. And for bridges where there is high strength and durability requirements, a higher grade of strength of concrete such as M60 or above can be seen in specifications. But

when you see the aggregate specification, there is be it any difference in terms of the performance requirement or the applications to which they have been put, the aggregate specification will be like plain and normal without having any performance oriented specifications there. So how does this affect is because we do recycling, the overall consumption can only increase because of the price effect due to market forces that we have seen.

That's one. And sometimes even the competition kind of shift from a high impact material to a completely low or lesser harmful material such as crusher dust and therefore can even display something which is less harmful than the real impacts that we generate because of pursuing recycling activities. Thus, recycling does not guarantee that we are going to displace primary production is a key message here. And this kind of is emanating because of the kind of engineering system view that we look at the system. For instance, whenever you look at from the use phases, whatever the material that has been discarded which are collected can actually be through either repaired or refurbished or put to recycling, people think that it will again keep going in these loops and therefore we may not be or we will probably be contributing environmental benefits to the environment. But what it is actually missing is the extraction phase that has to continuously happen because of the thermodynamic laws in which you nearly have to restrict levels of material that can be recovered through repair, refurbishment or recycling or any other R strategies.

And thus, this perspective of the economy kind of misses the overall point in terms of how the market sizes can grow and how we are continuously dependent on harmful primary production. So, in an economist view, whatever the R strategies that we look at, they always produce or contribute the products to a market, be it as a material market or a products market where the primary counterparts also come in and these products kind of compete with each other and the use phase kind of is taking its material dependence from the markets rather than whatever that has been from the recycling facility. And thus, the material markets and the role of market kind of influences which material to be displaced with respect to the competing product. So, to kind of summarize the lessons that we have discussed so far, let us take this curve where in the x-axis there is a production in terms of number of units and in the y-axis we are putting the impacts. And for a primary production activity, say pristine aggregates, the curve is usually steeper.

For instance, if you recall, it is about 12 kg CO_2 equivalents per kind of impacts that we generate for every ton of pristine aggregate production. Any circular economy activity such as recycling is actually aimed at slanting this curve so that per unit impact of recycling or production of secondary materials kind of is reduced and therefore we get some amount of benefits. For instance, an equivalent amount of production of primary product through the circular economy activity such as recycling kind of generates a reduced per unit impact of the overall production. And therefore, as compared to the earlier system, this is the potential benefit that we could see from pursuing recycling. But we have just seen that whenever recycling products are being put in the market, there is a market forces and there is a price effect loop that gets triggered and therefore the production is not really the same but it kind of increases.

So, because of the slight increase in the production, because of the increased supply of recycled aggregates in the materials market, we can see that the overall impact because of the overall system has now slightly increased and therefore there is a reduction in the potential benefit that we have seen earlier. And the benefits that are offset benefits that are offset because of the increase in production or consumption is termed as the rebound effect. This is the phenomenon because of which the overall benefits gets offset by the efficiency improvements such as recycling activities and the corresponding increase in the production or consumption. However, there might also be a case where your production kind of increase significantly because of which the resultant impact on the environment could stay at a level of E2, a new level, which can be higher than the earlier level where we did not have any recycling activity at all. And this is the situation which we term as backfire because while we thought that recycling could actually benefit the environment because of the market forces and the increase in the production and consumption, the overall net impact on the environment has actually increased and therefore the resulting recycling activity has actually produced a backfire effect.

To consolidate the lessons, the recycling activities can either raise or lower production quantities. And recycling activities, the secondary impacts of the relative to primary production can also be either lower or higher. So, if there is no change in production content is actually lower than the earlier system and your secondary impacts are producing recycled aggregates, let's say the impact is lower than the pristine aggregates, which means there is

lower. Then you have a lower net impact. So, this is actually a better system and whatever activities that kind of fall in this quadrant are actually better for the environment.

On the other hand, if your production quantities is not increasing, but your secondary impacts related to primary production is actually higher, let's say, then what it actually means is, for instance, in a reusable bottle, say as compared to something like a disposable bottle, where it is actually very lightweight, so the amount of material and therefore the embodied energy imparted in this product is actually very less. But if at all we design this bottle to be a reusable product, then we'll probably add more materials to it to make it durable. And because of that, it might become a bit more harmful as compared to a use & throw bottle. And in such a case, it is slightly higher in terms of as compared to use & throw bottle, is it not? Because it is competing with the use & throw bottle. And in such cases, the number of repetition with which we reuse this bottle will actually determine whether we have generated net impact on the environment or we have benefited the environment.

So, that is the quadrant that Q3 is talking about. If the secondary impacts are, for instance, recycling anything, the impacts is higher and the resulting production change quantity is also higher, which is kind of will going to produce a higher net impact on the environment, which is kind of undesirable. So, whatever that falls in this quadrant are not going to be useful at all. So, Q1 is the quadrant where it is characterizing the circular economy rebound, which means, even though there is an increased change in the overall production of quantities, your relative impact with respect to primary production is lower. For instance, in recycling it is just 5.

5 kgs you have to equalize. Therefore, in here, the overall production increase is going to determine to what extent. If the production increase is to such a level that the net impact on the environment has not gone up with reference to the earlier point of system, then we call this as a rebound effect. And if the production quantity increases significantly, this could actually result in backfire effect, which is a complete nullification of all benefits and rather it even affects the environment badly. So, this is a lesson from the kind of circular economy rebound and the role of market that it plays. So, what are the takeaways from this lecture? Recycling is not a silver bullet.

That is, it can never prevent end of life disposal. It only delays the time at which the disposal is going to happen. That is something that needs to be understood clearly. And the second

point is recycling will usually increase or impact increasing behavior. So, from the study in terms of the behavioural choice experiment study that we have seen, we tend to kind of consume more when recycling is as an option exists in before us. And therefore, we have to be conscious in

terms of consuming as well as we need to avoid any possible rebound effects as a result of the behavior that we are going to implicate.

For instance, the real focus should be on primary production displacement. How? As much of recycled aggregates has to be used in place of pristine aggregates. And for that, we should start rethinking the usage of pristine aggregates with respect to the performance requirements and specifications that are required for the applications to which it can be put. Only through conscious usage of pristine aggregates as well as recycled aggregates, can we really bring in primary production displacement. So, is reuse better? Of course, as per the waste management hierarchy, reuse is better than recycling.

But the thing to be noted here is the number of repetitions is going to actually determine whether we are really contributing positive to the environment or negative to the environment, depending upon the secondary impacts related to primary production impacts. And of course, at the top of primary waste management hierarchy is always the importance of waste reduction. So, our conscious choice should always be in terms of optimizing the primary production as well as the resources. And recycling or reuse always should be the second priority to waste reduction. With that, I would like to close this lecture with the message that consume less. Thank you so much.