Ex-ante LCA on an emerging electro-mass separation technology: The importance of the background system

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Abstract. Ex-ante LCA is a novel approach that provides a way to assess the eventual environmental performance of technologies that are currently under development. Between now and the investigated time several changes may have occurred to the fore- and background system, which may affect the results of the assessment. If this is the case, such changes should be integrated in to the life cycle inventory. The goal of this study was to determine how influential those changes are to the foreground system and if it is relevant to apply a cornerstone scenario approach when assessing potential changes. This is analysed using an emerging electro-mass separation technology as a case study. This technology can separate fly ashes based on their particle size. The main benefit of the technology lies in the ultra-fine fly ashes that are produced, which can be used to produce Ultra-High-Performance Concrete. Results showed a considerable difference between the reference and mitigation scenarios, and a smaller but still noticeable difference between the different mitigation pathways.

1 Introduction

To objectively assess the environmental performance of emerging technologies an ex-ante approach should be integrated in to life cycle assessment (LCA). Because of the novelty of ex-ante LCA, there is currently still a lack of uniformity among studies adopting the approach. Most of these studies tend to focus on upscaling the investigated technology while ignoring the potential changes to the background system and the incumbent system [1].

Taking changes to the background system into account is not an easy task. There are many different ways the future can go. While many industries and governments are putting forth plans to reach the current set climate goal by 2050, it is still uncertain if we might reach the target and if we do, how? This uncertainty can be taken into account by looking at not one but several "cornerstone" scenarios which outline a range of possible future pathways.

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In a previous study a prospective consequential background system of the cement industry was developed based on scenarios found in literature [2]. That study investigated a range of possible outcomes for the background system and the discrepancy between results. The goal of this study was to determine if changes to the background system end up having a substantial effect on the performance of the technologies in the foreground system and if it is relevant for the foreground system to take into consideration multiple scenarios for the background system. This is investigated with the use of a case study.

The case study is an emerging technology called the dusty cloud separator (DCS), developed by Value Ash Technologies (VASHT) NV whose environmental benefit has been assessed in a preliminary study [3]. This separation technology aims to increase the environmental benefit of class F fly ash in the cement sector. Class F fly ash is a waste product that mainly comes from the combustion of coal in power plants. Currently it is used by the cement and concrete sector to lower their environmental impact by substituting clinker in cement or cement in concrete. With the DCS the fly ashes are separated into three fractions based on their particle size. The finest fraction has characteristics similar to those of silica fume, a highly reactive pozzolan that is needed to produce Ultra-High-Performance concrete (UHPC) [4]. Unfortunately, silica fume, just as fly ash, is a waste product of which only a small amount is available [5]. With the DCS, an alternative to silica fume will be available, potentially leading to the production of more UHPC. This could lead to greater environmental benefit than with the current use of fly ash, as UHPC's bigger compressive strength compared to regular concrete allows for thinner profiles in structures and its increased durability also lowers the number of repairs and replacements that need to take place [6-8].

2 Methods

2.1 Goal and scope definition

The goal of the LCA is to assess the future environmental impact of fly ash undergoing classification using the DCS against the incumbent practice in which the fly ash is directly used in cement. The functional unit is therefore the treatment of 1 t of Class F fly ash. This is done based on a consequential modelling approach, in which marginal mixes are used and system expansion is used to deal with by-products [9]. ecoinvent 3.6 is used for the life cycle inventory. The assessment is performed using Recipe 2016 v1.1 hierarchist version [10]. Results are shown using the weighted single score.

In the current practice, fly ash is directly used in concrete to substitute ordinary portland cement (OPC) at a 1 to 1 ratio (see Figure 1). Using the DCS, the fly ash is separated into an ultra-fine, medium and coarse fraction (see Figure 2). The ultra-fine fraction can be used to produce UHPC which can be used instead of regular concrete in infrastructure projects such as bridges. Currently UHPC is produced using silica fume. As silica fume is a constraint product with low availability, it is assumed that any addition of ultra-fine fly ash onto the market will not result in a competition with silica fume, but instead in an increase in UHPC production. The potential environmental benefit gained from using UHPC instead of conventional concrete is therefore contributed to the ultra-fine fraction which allowed for this additional production of UHPC. The environmental benefit is calculated using a simplified version of a bridge as a case study [7]. The medium fraction has characteristics similar to those of unseparated fly ash and can just be used, as it is, to partially substitute OPC in concrete at a 1 to 1 ratio. The coarse fraction is too coarse to be used directly in concrete to substitute cement, but laboratory results have shown that with grinding it can be brought to the level of medium fraction and again substitute OPC.

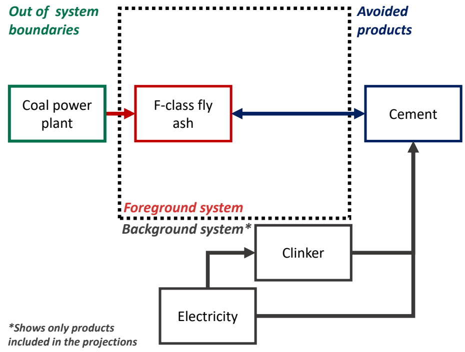

Figure 1 System scope of the incumbent technology

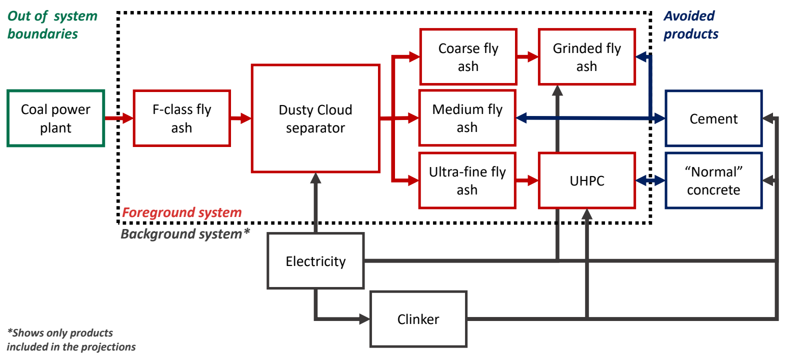

Figure 2 System scope of the innovative technology

2.2 Inventory analysis and scenario description

Foreground data are derived from the current pilot scale version of the DCS. In future work the technology will be upscaled with computational fluid dynamics to refine the results of the LCA. No big alterations are expected; however, as the developers estimate, the performance of the upscaled version will be very similar to that of the current pilot scale, in which fly ash is separated in to 20% ultra-fine, 65% medium and 15% coarse fly ash and the DCS requires 40 kWh electricity per ton fly ash treated.

The incumbent practice could potentially change in the future. Fly ash could be used in geopolymers or a new type of cement blends. However, from a waste treatment perspective nothing would change as in all cases fly ash will still substitute cement at a similar ratio.

Projections on development pathways were integrated for electricity and clinker for the EU (see Figure 1&2). Clinker was investigated, as it is the main component of cement, which is substituted by fly ash. Electricity was investigated as it is needed for the DCS to operate and will also become more important to clinker's environmental performance when electric kilns will enter the market. In the previous study, the climate goal scenarios for energy were taken from CLIMACT's Net Zero 2050 roadmap [11]. These consisted of three pathways to reach the set climate goal: a demand focused pathway, a technology focused pathway and a middle of the road pathway. Climate goal scenarios for clinker were taken from Material Economics and consist of one demand focused pathway and two technology focused pathways [12]. Both cement and energy used the JRC's reference scenario as the baseline scenario [13]. To limit the number of scenario combinations between cement and electricity only those scenarios with a similar focus where combined, resulting in 4 scenario combinations (see Figure 3).

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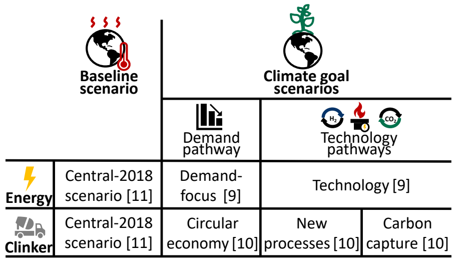

Figure 3 Overview of scenarios

While the industries themselves change quite a bit between the scenarios, the marginal mixes tend to be more similar. For electricity all scenarios focus mainly on wind energy (see Figure 4). For clinker, carbon capture is an important technology in all scenarios, though it is not fully needed to reach the climate goal (see Figure 5). For the reference scenario, carbon capture is not initially heavily pursued. In the last two decades the adoption rate, while still lower than in the climate pathways, is higher than the capital replacement rate, making kilns with carbon capture the marginal technology. On the energy side for the cement kilns the climate pathways focus on a combination of biomass and waste and electricity. However, as biomass and waste in the cement industries are constraint products that are popular in demand, they are excluded from the marginal mix leaving electricity as the marginal heat source for all pathways.

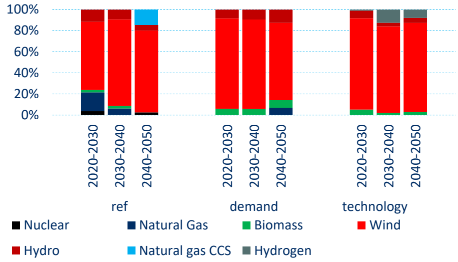

Figure 4 Marginal mix for electricity [2]

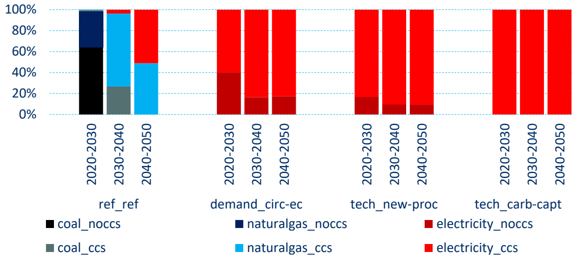

Figure 5 Marginal mix for clinker [2]

3 Results

Results show that fly ash separation provides a greater environmental benefit than the direct use of fly ash in cement and this for all scenarios and time periods. The effect of changes to the clinker market is the most pronounced in the results for the untreated, medium and coarse fly ash (see Figure 6). As untreated, medium and coarse fly ash are used to substitute cement; their environmental benefit is highly influenced by the environmental impact of clinker. This is why their environmental benefit is the highest in the current decade for the reference scenario as there is barely any carbon capture present in the marginal mix. For the ultra-fine fraction, the differences between the scenarios and decades are less apparent. As stated earlier, the environmental benefit of the ultra-fine fraction comes from the UHPC which can be produced with it and which can be used to replace regular concrete in structures such as bridges. In the investigated structure, quite a lot of reinforcing steel was used as well. UHPC requires the same amount of steel to be used compared to normal concretes. Yet, because of its higher durability, it does not need to be replaced during the bridge's lifetime unlike a bridge with regular concrete. This saves up not only on a substantial amount of cement but also steel. As steel was not considered in the projections, it is uncertain how much the environmental benefit of ultra-fine fly ash will vary over the different scenarios and decades.

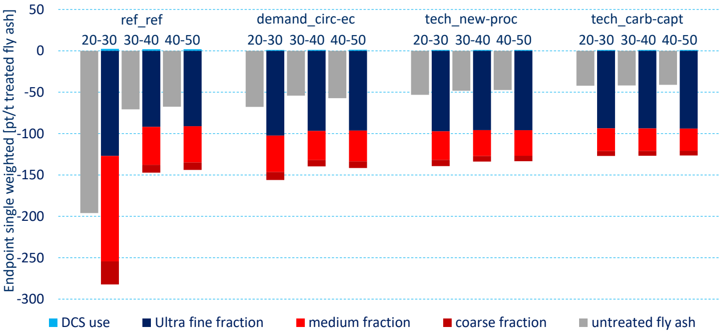

Figure 6 LCIA: untreated fly ash (incumbent practice) vs DCS treatment (innovative practice)

For the electricity mix, there are no big differences between the 3 climate goal pathways and between their investigated time periods. There are however noticeable differences between the baseline and climate goal pathways. This can be seen in Figure 7, where the impact of the electricity mixes on the foreground was investigated for the reference cement scenario and a climate goal cement pathway. The results show that the differences between the reference and technology pathway do show up in the foreground system.

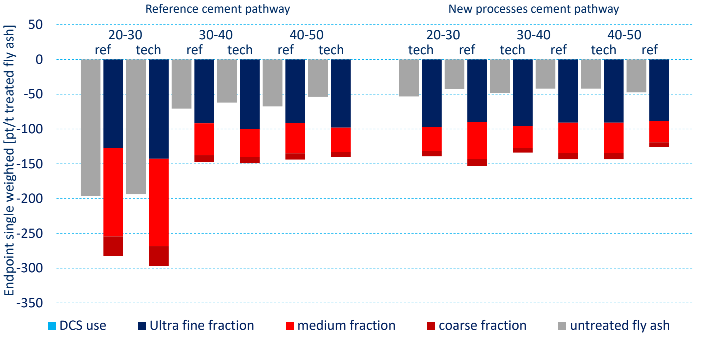

Figure 7 LCIA: Impact of the electricity pathway on the foreground system

4 Discussion and conclusions

Results highlight the importance of incorporating projections into the background system. The reference scenario for the first decade most closely resembles our current situation. Not taking projections for the background system into account can in this case result in an overestimation of the environmental benefit with a factor 4 when looking at the incumbent practice and with a factor 2 when looking at the innovative practice.

The underlying assumptions of the projection have a substantial effect as well. Within the cornerstone scenario approach, it seems especially important to include minimum and maximum effort scenarios to reduce our environmental impact (i.e., reference and climate goal scenarios). This is the case for both clinker and electricity. The differences between the climate goal pathways are less prevalent but still noticeable even though clinker production has only two ways in which it can change (heat source and adoption of carbon capture), there is still a noticeable difference between all scenarios. Going from clinker to cement and concrete, it is expected that these differences will only increase as pathways differ in SCM use, the adoption of several novel binders to replace cement and optimization of the concrete mix. For electricity however the differences between climate goal pathways seem minimal.

To further refine the background system, potential changes to steel should be included as it has a significant contribution to the environmental benefit of the ultra-fine fly ash fraction.

Current projections focus on Europe only, however as coal power plants are expected to phase out even in the baseline scenario, the potential to use the technology here is minimum. Despite coal power plants global decline, some regions are still expected to have considerable capacity. Examples of these are South Africa, India and China which all have plans to install new capacity [14, 15]. Future work will investigate which regions are most promising to use the DCS in, taking into account the different ways the future may develop.

In the current approach, projections originate from several roadmaps found in literature. As each roadmap uses its own underlying assumptions to develop the pathways, care has to be taken when linking the scenarios of different industries. In this study, the pathways were linked based on their focus (i.e., demand or technology), but there is not always a direct correlation between what one industry focusses on versus another. Not having this link between industry's roadmaps also means that cross-sector effects are not taken into account, such as the impact of electricity price on the adoption rate of electric kilns or the availability of constraint products. The same holds true for cross regional effects such as trade.

A way to solve these problems is by having scenarios based on a single global model. Examples are IEA's world energy model [16], The Global Calculator [17] and Climate Analytics' national pathway explorer [18]. Especially interesting are scenarios developed with an integrated assessment model (IAM) using the shared socioeconomic pathways (SSP) [19] and representative concentration pathways (RCP) [20] as input. These look at a wide range of how the world may develop disaggregated into regions and with a decent technoeconomic resolution. These scenarios have in the past been incorporated in LCI databases, but only for attributional LCA [21]. Future research will therefore focus on developing a prospective consequential LCI database based on the IAM scenarios.

In the previous study, which this study is a continuation of, it was decided to focus on the consequential approach [2]. This approach is particularly suited for decision making as it allows the user to investigate the consequences of a possible change, in this case the substitution of the incumbent technology with the emerging technology. However, the findings of this study would still largely stand when using an attributional approach. Using the attributional approach, the results will likely show a more gradual change in market share and environmental impact throughout the years. This is especially the case for pathways involving phase outs. The differences between climate goal pathways would also likely be more pronounced when using an attributional approach, especially if there are pathways which rely heavily on constraint recourses as was with the case of cement which used biomass and waste in various degrees throughout the pathways.

To conclude, this study has demonstrated the importance of the background. More work is required to develop a consequential prospective background system as the current approach lacks consistency between the scenarios of industries and regions. Future research will aim to include the potential interactions between industries and regions by developing a global database using the SSP x RCP scenarios.

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