Interim Report | August 2022

Plastic Credits – Financing the Transition to the Global Circular Economy

Interim Report on the Pilot Regions Goa, Maharashtra, Kerala

rePurpose

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1 Interim Assessment Report

Growing amounts of plastic waste are a significant issue in India's semi urban areas, as described in the baseline report.[1] This also is the case for the three pilot regions - Goa, Aurangabad (Maharashtra), and Kerala. According to that report, only 3.6 % of generated multilayer plastic waste (MLP) is currently collected in India, which implies that the remaining 96.4 % of waste is being dumped into the environment or burned in an uncontrolled way. This number is supported by a study of the United Nations Economic and Social Commission for Asia and the Pacific, which claims that more than 70 % of solid waste is openly dumped in India.[2]

Issues with openly dumped waste involve the terrestrial, as well as the marine environment. Marine plastic waste mainly originates from land-based sources such as mismanaged waste from open dumpsites close to coasts and riverbanks, beach littering, fishing industry activities or other industrial sources.[3, 4] Being located at the Arabian Sea with long shorelines, plastic marine debris is considered a serious issue for all three pilot regions.[5]

The Baseline Assessment Report stated that the share of collected MLP in Goa is 11 % and thus above the Indian average of 3.6 %.[1] However, by being a popular tourist destination, Goa faces a heavier pollution by plastic debris on coasts than other areas.[5] If the beach litter is not collected on a regular basis, it has a big potential to add to the issue of marine plastic pollution.

In semi urban areas of Maharashtra, on the other hand, a lack of infrastructure for collecting and separating plastic waste has been noted. An estimated amount of 13 kt of MLP waste is generated yearly and so far none of this MLP waste is collected and separated for further processing.

Kerala too is struggling to implement the infrastructures needed for the collection of solid waste in general, and thus plastic waste as well. The resulting waste contamination has led to some efforts for improving this situation which still requires further development.

Within the framework of this project, a value chain for the collection and treatment of plastic waste from households in the three pilot regions was set up. As already mentioned in the Baseline Assessment Report, the project thereby focuses on low value plastics (LVP) and especially MLP with no market value. [1] Through the implementation of this project, these plastics are now collected and treated by being *co-processed* in a cement kiln (i.e. used as substitute fuel) or by being *reprocessed* (i.e. mechanically recycled). However, it should be noted that most of the collected waste comprises MLP that is not suitable for recycling and hence, is being co-processed.

The project activities on site started in April and will be carried out until the end of September 2022. For each month, the local partners report the amount of LVP (including MLP) that was collected, sorted and treated, as well as the number of workers directly involved in the process. It is anticipated that the activities will reduce the amount of plastic waste that would otherwise be burned or dumped, and by the latter leaked into the environment and the ocean. Furthermore, a raise in awareness of the semi urban population is expected towards the issue of plastic waste and its environmentally friendly disposal.

As part of the project, we strive to understand, which effects the activities on site have on different environmental factors. In order to do so, an Environmental Impact Assessment (EIA) is conducted addressing the ecological and social impacts of the project. The outcome of the EIA could be used to improve the setup of the waste management infrastructure within those regions. Further, the results could be transferred to other projects with a similar setup. Herein, we want to stress that the assessment is restricted to the analysis of the project implementation financed through plastic credits. Specifically, it does not account for impacts outside of the regional framework and hence does not consider implications that might occur on the other end of the chain, at the company level, for instance, that decides to invest into plastic credits.

The following report provides details of the project setups in the three pilot regions. Section 2 includes the first data received for April, i.e. the amount of collected plastic waste and the number of workers directly involved with the management of the waste. This is followed by the methods section 3. Here the EIA and its approach is explained in detail. In the last section 4, the Environmental Impact Assessment Matrix - that was developed in order to structure the assessment - is described as part of the results (section 4.1), as well as first calculations for the analysis of the project's impact on the change of CO_2 emissions (section 4.2).

The final assessment (which includes the calculations for the CO_2 emissions corresponding to the total amount of treated LVP throughout the project) will be conducted, once the data covering the entire project phase has been generated. This final assessment will be presented in the Final Report.

2 Project setups in the pilot regions

The project setup on site is organized and supported by the project partner rePurpose, who is additionally providing a financial mechanism on these activities through a plastic credit scheme.

2.1 Project setup in Goa

Activities in Goa are managed by the local partner vRecycle. Figure 1 shows the value chain that has been set up in the region, it covers the management of end-of-life plastics. Since April, MLP and other LVP are being collected from households in different villages in Goa. In the first reporting month of April, 11 workers were directly involved in the collection of the waste. The collected waste is transported to a Material Recovery Facility (MRF) that partners with vRecycle. There it gets sorted and baled. Another 14 workers are employed in this process. Finally, the plastic waste bales are sent to either the Dalmia Cement kiln or the JK Cement kiln, both in the neighboring state Karnataka, where the waste is being used as substitute fuel. In April, about 68 tons of LVP were collected of which 99 % were co-processed in the cement kilns.

Figure 1: Value chain for the management of plastic waste in Goa. Figure by rePurpose.

2.2 Project setup in Aurangabad - Maharashtra

EcoSattva operates the site activities in Aurangabad - Maharashtra. Figure 2 shows the implemented waste management infrastructure for this region. People are working in the collection, sorting and baling of the waste. In April, a total of 109 workers were involved in the processes, 78 of them in the collection of waste from households within the local municipalities. The waste is sorted by hand at the EcoSattva facility in Aurangabad. It comprises mostly MLP (in April about 87 %) and some small amounts of other dry waste and mixed plastics. After baling, everything is sent to be co-processed in the Ultratech Cement factory in Chandrapur, Maharashtra. In April, almost 66 tons of LVP waste was collected in Aurangabad and sent for further treatment to the cement kiln.

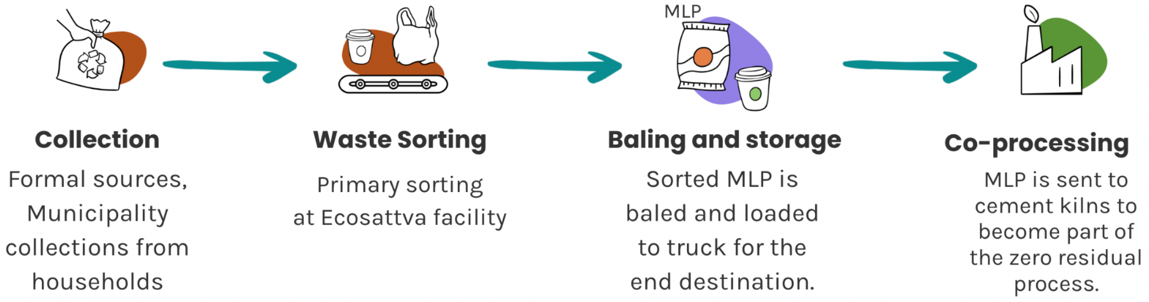

Figure 2: Value chain for the management of plastic waste in Aurangabad - Maharashtra. Figure by rePurpose.

2.3 Project setup in Kerala

In the region of Kerala, the project operations are managed by Greenworms. Figure 3 shows the corresponding value chain, which involves all steps from the collection to the final treatment of plastic waste. In April, a total of 364 workers were directly involved with the different activities. Most of them (270 workers) are organized independently of the project in women self-help groups that collect the waste from households. In cooperation with Greenworms, they collect LVP, which in April consisted of 60 % MLP. After the collection, the waste is sorted by hand in two steps at a Material Collection Facility (MCF) and Greenworm's MRF into two fractions. One comprises MLP and the other one consists of recyclable plastic waste. The latter is sent to the recycling facility VP Plast in Chennai, where the waste is mechanically recycled into granulates. The other part, which consists of MLP, is not suitable for recycling and is therefore sent to either the Dalmia Cement or the Ultratech Cement factory in the neighboring state Tamil Nadu where it is used as substitute fuel. In April, more than 208 tons of low value plastics were collected, out of which 39 % were recycled and 60 % were co-processed in the cement kilns. The missing 1 % comprises losses within the process.

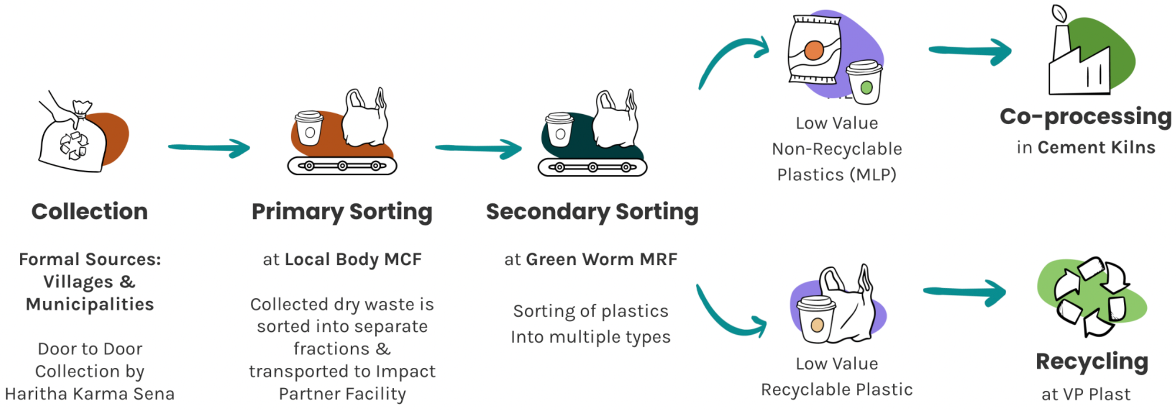

Figure 3: Value chain for the management of plastic waste in Kerala. Figure by rePurpose.

3 Methods

3.1 Environmental Impact Assessment Matrix

As motivated in the Baseline Assessment Report [1], the EIA for this project is structured by an Environmental Impact Assessment Matrix (EIAM).[6] This EIAM contains the relevant project activities on as rows and the environmental components as columns. The components thus cover the impacts that are generated by the project activities on the environment. For a visualization of this matrix see also Table 1 in the Baseline Assessment Report.[1]

In the first step, both the main activities and components were identified. Following the approach of the Rapid Impact Assessment Matrix [7], the environmental components were then clustered into four categories:

a. **Physical/Chemical** (covers physical and chemical aspects of the environment),
b. **Biological/Ecological** (covers biological aspects of the environment),
c. **Sociological/Cultural** (covers human aspects of the environment, including cultural aspects),
d. **Economic/Operational** (covers economic consequences of environmental change).

Furthermore, the components were differentiated between *direct* and *indirect* impacts. The *direct* impacts were defined by taking the direct social and environmental impacts of the project into account, e.g. the creation of jobs along the value chain or the saving of raw materials - like coal - through the utilization of plastic waste as substitute fuel in cement kilns. In this way, three direct environmental impacts were identified.

Next to the direct impacts, the project also causes *indirect* environmental impacts given the fact that the plastic waste, if not collected, would be openly burned, or dumped in the respective regions. This would lead to plastic pollution on land as well as in the ocean due to the proximity of the pilot regions to the coast (see also Section 1). Against this background, a literature review on the main environmental impacts of marine and terrestrial plastic pollution was carried out through which the main indirect impacts were identified (CO_2 Emissions, raw-material usage, and employment).

After determining the project activities and environmental components, a potential correlation was assessed between each activity and environmental impact and marked accordingly within the matrix. In this way, by providing an overview of project activities, environmental components as well as their linkages, the matrix clearly structures the EIA. The EIAM is presented in Section 4.1 of this report.

In the Final Report, each identified correlation within the matrix will be analyzed. For two out of the three direct impacts (the *change of* CO_2 *emissions* and the *usage of raw materials*) this will be done in a quantitative way by using the data that will be gathered throughout the implementation phase of the project. For both of these impacts, the methods for the calculations are described in detail in the respective subsection below. The linkages between project activities and other impacts, on the other hand, will be analyzed qualitatively by carrying out a literature review on the topic of the respective environmental impact focusing on the South Asian region and India specifically.

In the following two subsections 3.2 and 3.3, the methods for the assessment of the two environmental components, the *change of CO_2 emissions* and the *usage of raw materials*, are described in detail.

3.2 CO_2 emissions

One direct impact of the project activities on the environment is the change of CO_2 emissions when the plastic waste is mechanically recycled or used as substitute fuel in cement kilns. In order to calculate this change, possible emissions and their magnitudes were analyzed along the value chains that were set up for the treatment of waste in the three pilot regions. Hence, this subsection 3.2 is divided into four parts:

- Emissions from plastic waste collection and logistics,
- Emissions from co-processing of plastic waste in cement kilns,
- Emissions from recycling of plastics,
- Emissions from usage of plastic waste for road construction (as this might comprise a possible alternative to the current treatment).

3.2.1 Emissions from plastic waste collection and logistics

In principle, CO_2 emissions are caused by the collection and processing of waste as well as its transport. The collection and transportation of waste includes the aspects shown in Figure 1, 2 and 3:

1. **Collection of waste** - is done manually without significant use of consumables, emissions are assumed to be negligible,
2. **Transportation to MCF**,
3. **Sorting at MCF** - is done manually, emissions are assumed to be negligible,
4. **Transport from MCF to MRF**,
5. **Secondary sorting at MRF** - is done manually, emissions are assumed to be negligible,
6. **Transport to final treatment destination** - either the cement kiln or to the recycling facility.

Figure 4: Sorting and transport of plastic waste. Figure by rePurpose.

As the collection and the sorting of waste is done manually (see also Figure 4), the emissions of these processes are assumed to be negligible. In order to calculate the emissions of waste transportation, the distances between the MSF and the cement plant needed to be determined. A list is shown in Table 4 in the results section further below (see Section 4.2). The distance can then be multiplied by the emission factor for the transport. Data on emissions from transport in India is provided, for instance, by Singh et. al, Badyia and Borken-Kleefeld, or for German vehicles by the HBEFA database.[8–10] In this document, emissions were assumed to be 900 g/vehicle_kilometer and the effective load per trip to be 15 t. This results in an emission factor of 60 g/(t*km), which was multiplied by the traveling distance between the MRF and the final treatment destination in order to calculate the emissions that are caused by the transportation of the waste in the three pilot regions.

3.2.2 Emissions from co-processing of plastic waste in cement kilns

If plastic waste is used as fuel in the production of cement, it substitutes fossil fuels such as coal and gas. The paragraph below gives a short overview of the process steps that are important for the calculation of greenhouse gas (GHG) emissions from cement production.

Cement consists of ground cement clinker and is produced from the raw materials calcium carbonate and clay minerals. The clay minerals contribute the substances silicon dioxide and, in smaller quantities, aluminum oxide and iron oxide to the process. In simplified terms, at the elevated temperatures in the cement kiln, the calcium carbonate (limestone, $CaCO_3$) is first calcined and converted to calcium oxide (quicklime, CaO):

$$CaCO_3 \text{ - - -> } CaO + CO_2 \qquad T > 850\ °C.$$

The calcium oxide then sinterizes with the other components at temperatures of approximate 1450 °C and forms the cement clinker. These high temperatures required for the phase transformation make the process extremely energy intensive and cause high GHG emissions. In addition, the calcination of the limestone releases CO_2, which leads to further significant emissions. The CO_2 emissions from calcination cannot be prevented when $CaCO_3$ is used as feedstock and may be used by carbon capture utilization (CCU) in perspective.

The high temperatures in the process are generated by firing with fossil primary energy sources. For illustration, the process is shown in Figure 4. Process optimizations such as pre-drying and calcination using waste heat as well as process control to reduce the emission of nitrogen oxides can reduce the emission significantly. Ultimately, the process always remains a source of GHG emissions because of the endothermic reaction and the emissions from calcination. Even with optimized process control, the energy consumption is at least 2900 $MJ/t_{clinker}$. Due to the high process temperatures, emission reduction through the use of electrical heat is only possible to a very limited extent. The use of regenerative fuels such as methane or hydrogen is conceivable in principle but not yet economical. On the other hand, due to the high temperatures, the process is suitable for the combustion or co-combustion of waste or residual materials that cannot be discarded in another fashion. Materials that are to be used as fuel in primary combustion must have a sufficiently high calorific value (lower calorific value H_u >= 22 MJ/kg) and be available in a suitable form as dust or granulate. These requirements are necessary for the material in order to be burned in the main flame of the rotary kiln, as the maximum achievable temperature depends on the calorific value of the fuel. Plastic waste is particularly well suited for this application given its sufficiently high calorific value. Waste with a lower calorific value can also be used in secondary firing.

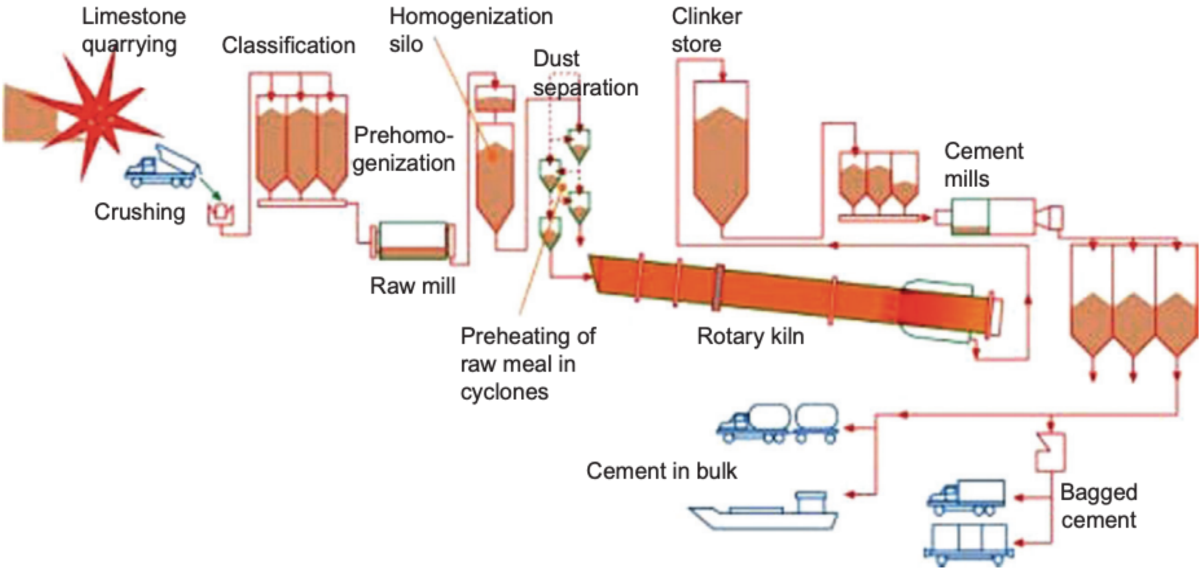

Figure 5: Cement production. The raw materials are fed into the crusher, crushed, homogenized, dried and then burned in the rotary kiln. The clinker produced here is ground into cement, mixed with aggregates and shipped.[11]

The CO_2 emissions of a cement plant (GHG_{Total}) can be calculated in its simplest form depending on the system boundary drawn as follows from the emissions from the calcination reaction ($GHG_{\text{Calcination}}$), the emissions from the use of raw energy ($GHG_{\text{raw-Energy-use}}$) and other emissions ($GHG_{\text{other}}$):

$$GHG_{\text{Total}} = GHG_{\text{Calcination}} + GHG_{\text{raw-Energy-use}} + GHG_{\text{other}} \quad (1)$$

For simplicity, we can assume that only the term $GHG_{\text{raw-Energy-use}}$ changes when fuels are partially replaced by collected waste. Therefore, the calculations in the result section (Section 4.2) refer only to this part of the emissions. Due to the use of collected MLP waste instead of other fossil fuels, the change in CO_2 emissions (ΔGHG) results from the difference in the calorific value-specific emission factors for fuels and for MLP and is calculated by the following equation (2):

$$\Delta GHG = \textit{calorific-value-specific-emission-factor}_{\text{fuel}} - \textit{calorific-value-specific-emission-factor}_{\text{MLP}} \quad (2)$$

Hence, as preparation for the calculation of changes in CO_2 emissions, the calorific value-specific emission factors for different fuels and plastics were determined. They are presented in Table 4 in Section 4.2. In the final assessment, this list will be used in order to calculate the absolute difference of CO_2 emissions at the end of the project implementation phase when the total amount of MLP that was co-incinerated in cement kilns is known.

3.2.3 Emissions from recycling of plastics

In the case of Kerala, parts of the collected plastic are currently sent to a recycling facility where the material is mechanically recycled. If the recyclate produced in this way is used to replace other plastics, this process results in CO_2 savings. This is based on the fact that less greenhouse gasses are emitted for the production of the recyclate, than for the production of an equivalent amount of virgin plastics. To calculate the CO_2 emissions saved in this way, the difference between the emission factors of the raw material that is being replaced and the recycled material can usually be used. This difference may need to be multiplied by a correction factor to account for the fact that the mass of material used increases slightly due to the properties of the recycled material. The waste considered here is not a mono-material but a mixed fraction of different plastics. Since it was not possible to obtain data on the consumption of the recycling plants on site, an estimate was made on the basis of data collected elsewhere.[12] The data is visualized in Figure 6 below.

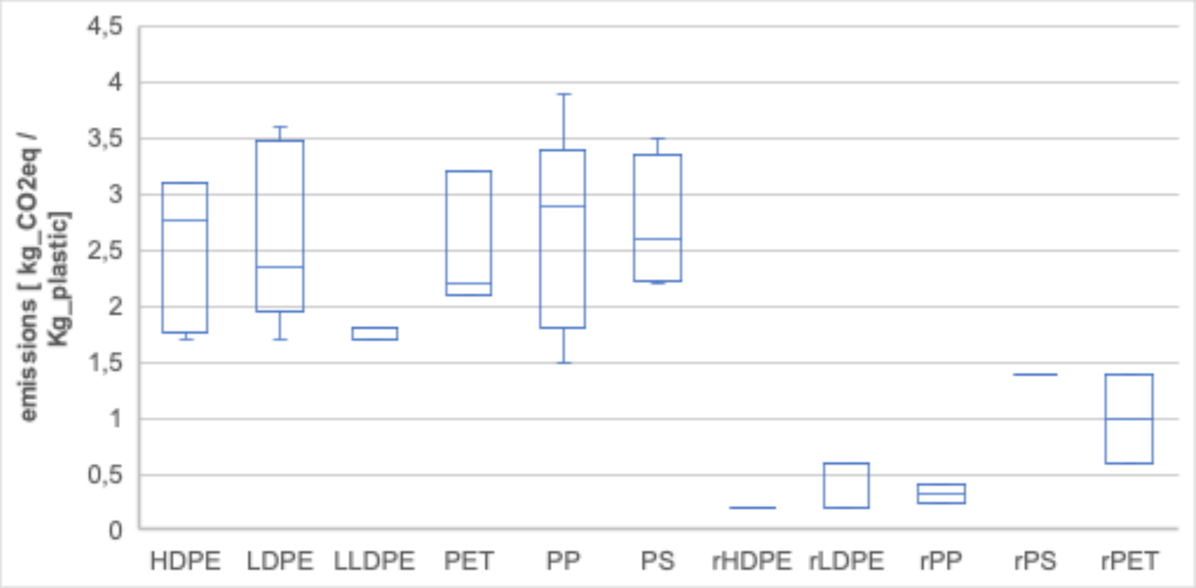

Figure 6: GHG emission factors of different plastics and recycled plastics [12]

As it can be seen, there is a high bandwidth (sometimes a factor of 2) between the different values. This is most likely due to different system boundaries and allocations of the underlying studies. For the estimation carried out here, it was assumed that the CO_2 intensity of the replaced plastic corresponds to that of LDPE. Additionally, the emissions from the recycling process had to be estimated. For this purpose, a weighted average of the emission factors of the plastics rHDPE, rLDPE, rPP, rPS and rPET was used, see Table 1. The share values refer to the estimated proportions in the collected, film-heavy waste. The following proportions were assumed: HDPE 10 %, LDPE/LLDPE 45 %, PP 15 %, PS 5 %, PET 25 %, recycled content 0 %. The values assumed as emission factors can be found in the table below. The weighted emission factor for plastic from the collected waste is 0.66 $kg_{CO2eq}/kg_{plastic}$, which is very close to the emission factor of the main component rLDPE/rLLDPE of 0.6.

Table 1: Calculation of emissions for mixed recycled plastics

plastic	share	emission factor [$kg_{CO2eq}/kg_{plastic}$] [12]
rHDPE	0.1	0.2
rLDPE	0.45	0.6
rPP	0.15	0.3
rPS	0.05	1.4
rPET	0.25	1
weighted sum		0.66

The plastic recovered from these fractions is usually subject to considerable downcycling and is used with high filler contents as a substitute for materials such as concrete or wood. It is used in applications such as palisades, grid slabs, paving stones, planks, floorboards or outdoor furniture. The savings in emissions from the use of recycled materials can only be obtained if the material that is replaced in the production process is known.

3.2.4 Emissions from usage of plastic waste for road construction

Another possible sink for plastic waste is the use as filler in road construction. It is evaluated here since it is a possible alternative to the co-processing in cement kilns and used in the pilot regions for example in Maharashtra. In this technology, developed in India, plastic waste is mixed with bitumen and then used to build local, minor roads.[13] Through this use, unlike co-processing in cement kilns, the carbon bound in the material is sequestered instead of being released as CO_2. The consideration of the CO_2 emissions will therefore most likely be more positive in this case.

The system boundaries drawn here are shown in Figure 7. The following steps are included in the evaluation:

1. The collection and logistics of the plastic waste,
2. The production of the bitumen,
3. The use in road construction.

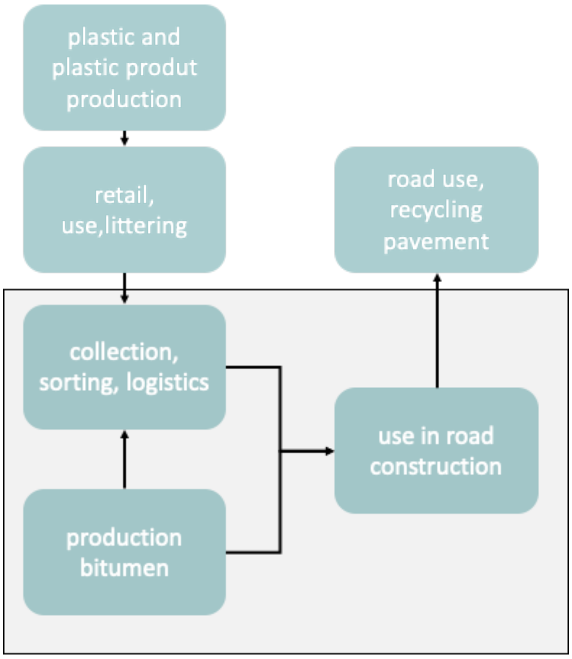

Figure 7: Processes under consideration, the gray box shows the scope used in this report.

Since the plastic is not explicitly produced for the use in road construction, its production and use before collection as waste are not taken into account here. Similarly, differences in the use, service life or disposal of road pavements with or without plastic are not considered.

Plastic is added to bitumen in a ratio of 8 %. It is assumed that bitumen is replaced by plastic in a weight ratio of 1:1. The resulting relative savings can thus be calculated from the weight-specific emission factors using the following formula:

$$\Delta GHG_{\text{relative}} = GHG_{\text{bitumen}} / (GHG_{\text{bitumen}} * 0.92 + GHG_{\text{collection}}) \quad (3)$$

Rearranging the equation and substituting ΔGHG with 1, yields the maximum GHG emissions that can be produced by collection and sorting ($GHG_{\text{collection}}$) from a sustainability viewpoint, 8 %. This value was calculated into its emission equivalent in Section 4.2.

3.3 Substitution of raw materials

In the three final treatment options that are considered in this report (i.e. co-processing in cement kilns, mechanical recycling, bitumen substitution for road construction), the waste is used to replace raw materials. These are fossil fuels (when the plastic is being burned in cement kilns), materials such as wood, concrete or virgin plastic (when it is mechanically recycled), or bitumen (in the case of road construction). In order to calculate how much fuel was saved, the mass specific heating values of the materials can be used. The other materials are replaced on a gravimetric or volumetric base assuming that dimensions are the same in the product made from recycled plastic as in the original one, this holds true e.g. for palisades.

4 Results

This Section will first describe the Environmental Impact Assessment Matrix that was developed for the EIA of this project (Section 4.1). The linkages of project activities and environmental impacts that are captured by the EIAM, will be described and analyzed in detail in the final report of this project. However, first results on the topic of CO_2 emissions are presented (Section 4.2). These will be used in the final assessment in order to calculate the change of CO_2 emissions by the transportation of the plastic waste, by its use as substitute fuel in cement kilns, by recycling it and as alternative to the current set up by the usage of the waste in road construction.

4.1 Environmental Impact Assessment Matrix

Table 2 shows the developed EIAM that contains the main project activities, potential environmental impacts and linkages between the two characteristics. The similarities across all three project setups allowed the development of one single matrix covering all relevant aspects. The project activities are oriented along the value chain for the waste management and hence, cover first, the collection of plastic waste, second, the segregation and pre-processing, third, the co-processing of plastic waste in cement kilns, and forth, the recycling of plastic waste. Note that the recycling of plastic waste comprises the only example of an activity that is not relevant for all regions as it takes place in Kerala only (see Section 1).

Table 2: Environmental Impact Assessment Matrix with correlations between the considered project activities and environmental components.

Project activities / Environmental components	Collection of LVP	Segregation and pre-processing of LVP	Co-processing of LVP in cement kilns	Recycling of LVP (Kerala only)
Physical / Chemical				
CO_2 emissions (direct)			✓	✓
Usage of raw materials (direct)			✓	✓
Biological / Ecological				

Marine wildlife (indirect)	✓			
Terrestrial wildlife (indirect)	✓		✓	✓
Sociological / Cultural				
Employment (direct)	✓	✓		
Health (indirect)	✓		✓	✓
Economic / Operational				
Fishing industry (indirect)	✓			
Tourism (indirect)	✓			

Concerning the environmental components, for each category (Physical/Chemical, Biological/Ecological, Sociological/Cultural, Economic/Operational) two different aspects were identified and considered in the assessment. It should be noted that this list might be extended by other environmental components since the impacts of plastic pollution on the environment are numerous. It, however, covers the aspects that were identified as crucial and most important.

The three direct environmental components cover:

(1) the change of CO_2 emissions through the setup of the waste management value chain in comparison to the previous status,
(2) the saving of raw materials through the co-processing and recycling of plastic waste. The material would otherwise have been burned or leaked into the environment (see also Section 1) and by that the material would have been lost,
(3) the creation of employment for workers, that collect the waste and those that segregate and pre-process the waste before it is transported to the cement kilns or recycling facilities.

Furthermore, five main indirect components were identified by a literature review on environmental impacts caused by plastic pollution. These are indirectly linked to the project activities since the collection and treatment of plastic waste prevents the litter from being openly burned or dumped in the environment. These indirect components include the impact by plastic waste debris and microplastics on (1) marine wildlife as well as on (2) terrestrial wildlife, the impact of openly dumping and burning plastic waste on (3) the health of humans (and terrestrial wildlife), as well as the economic impact of marine plastic litter on (4) the fishing industry and (5) tourism.

4.2 CO_2 emissions

4.2.1 Emissions from plastic waste collection and logistics

Multiplying the emission factor presented in the method section (see section 3.2) by the distance between MRF and final destination, the emissions for the transport of the plastic waste were calculated for each region. The results are shown in Table 3. When comparing with the emissions from co-incinerating plastic waste in cement kilns (see next chapter), it becomes apparent that the emissions from transport only amount to 0.5 - 1.0 % and thus are nearly neglectable.

Table 3: GHG Emissions of collected LVP transportation.

Organisation	**Name of end destination**	**Location of end destination**	**Distance from MRF to end destination (in km)**	**GHG emissions [$kg_{CO2}/kg_{plastic}$]**
EcoSattva (Aurangabad, Maharashtra)	Ultratech Cement (Aditya Birla)	Chandrapur, Maharashtra	470	0.028
vRecycle (Margaon, Goa)	Dalmia Cement	Dalmia Cement Bharat Ltd. Yadwad Village, Belgaum, Karnataka	226	0.014
	J.K. Cement	Muddapur, dist. Bagalkot, Karnataka	231	0.014
Greenworms (Mallapuram, Kerala)	Dalmia Cement	Dalmiapuram, dist. Trichy, Tamil Nadu	391	0.023
	Ultratech Cement (Aditya Birla)	Reddipalayam Post, Ariyalur dist. Tamil Nadu	423	0.025
	VP Plast (recycling facility)	Chennai, Tamil Nadu	235	0.014
Tharamassery (Kerala)	Ultratech Cement (Aditya Birla)	Reddipalayam Post, Ariyalur dist. Tamil Nadu	452	0.027
	Dalmia Cement	Dalmiapuram, dist. Trichy, Tamil Nadu	423	0.025

4.2.2 Emissions from co-processing of plastic waste in cement kilns

Equation (2) in section 3.2 is used in order to calculate the change in GHG emissions (ΔGHG) caused by the co-processing of plastic waste in cement kilns. Therefore, the calorific value-specific emission factors for fuels and MLP are needed. These can be taken directly from the literature, if they were published. Otherwise, they can be calculated from weight-specific emission factors and calorific values. Depending on the cement kiln, different fuels or mixtures thereof are used. A general statement on the change in emissions is therefore not possible or highly simplistic. However, by comparing the combustion of plastic waste with the combustion of various other fuels, the range of possible changes in emissions can be shown. Table 4 shows in the first column a selection of fuels that are used in cement kilns, other fuels, and possible substitute fuels. For most of the materials, a lower heating value can be determined; for fossil fuels and some of the substitute fuels, data for fuel-specific emissions are also available. For the pure plastics marked by "own calculations", the weight-specific CO_2 emissions were calculated from the carbon content of the plastics using the following formula:

$$\textit{Emissions} = \textit{molar-mass-carbon-content-in-the-repeat-unit} * (44/12) / \textit{molar-mass-repeat-unit} \quad (3)$$

Fillers or additives were neglected, an assumption permissible due to the low mineral filler content in the plastic fraction studied here. Any residual moisture content of the plastic waste was not taken into account, this would reduce the calorific value of the waste and increase emissions. The results of the calculations for each fuel are shown in Table 4. For a selection of fuels, the results are additionally visualized in Figure 8.

Table 4: Calorific values, weight-specific emission factors, and calorific value-specific emission factors of different fuels and plastics as substitute fuels. Own calculations are marked with *.

Fuel	Calorific value [MJ/kg]	GHG emissions [kg_{CO2eq}/kg]	GHG emissions [kg_{CO2eq}/MJ]
Natural gas			0.0560[14]
Gas from pressurized oil cracking			0.0881[14]
Gas from pressurized natural gas reforming			0.0664[14]
Gasoline			0.0731[14]
Gasoline			0.0720[15]

Diesel			0.0741[14]
Diesel			0.0740[16]
Waste oil	30[17]		
Heavy fuel oil			0.0813
Heavy fuel oil			0.0780[16]
High-grade coal, Germany (*Vollwertkohle*)	28.3[17]		0.0930[16]
Anthracite	34.361[14]		0.0968[14]
Anthracite	30[18]		
Egg coal, England	31.496[14]		0.0959[14]
Lignite - high emissions	18.65[14]		0.1003[14]
Lignite - low emissions	20[14]		0.0929[14]
Lignite	24[18]		
Mixed plastic	35[19]	2.9[20]	0.0829
Mixed plastic	38.94[21]		
Mixed plastic	34[18]		
Mixed plastic	23[17]		
Mixed plastic packaging waste	20[16]		
Plastic foil	37.7[18]		
PE - polyethylene	46.1[22]	3.14*	0.0681
PE - polyethylene	43[19]	3.14*	0.0730
PP - polypropylene	44[22]	3.14*	0.0714
PET - polyethylene terephthalate	20[22]	2.29*	0.1145
PS - polystyrene	40.2[22]	3.38*	0.0841
PVC - polyvinyl chloride	18[22]	1.41*	0.0783
Scrap tires	33.1[18]		

Textiles waste	30[17]		
Municipal solid waste	10[19]		
Pulp, paper, cardboard	5[17]		

From the values and visualization in Figure 8, it is clear that the magnitude of plastic combustion emissions is in the same order of magnitude as emissions from the burning of fossil fuels. However, depending on the fuel used, savings in CO_2 emissions are possible, for instance when replacing coal or emission-intensive gas.

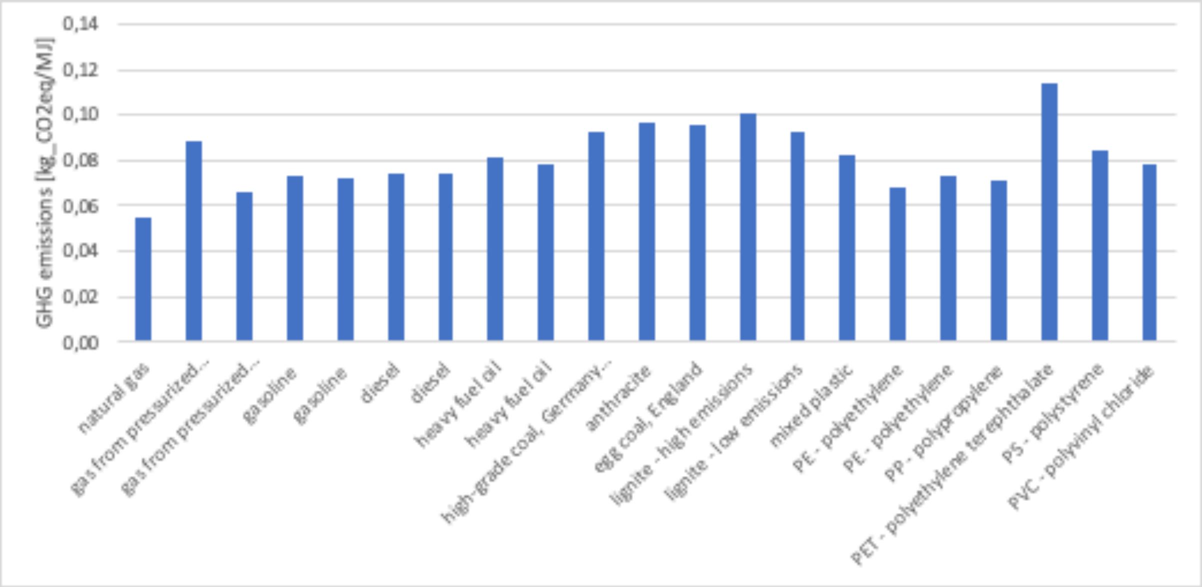

Figure 8: Emission factors of different fuels and plastics as substitute fuels, own visualization based on Table 4.

4.2.3 Emissions from usage of plastic waste for road construction

GHG emissions from the production of bitumen are in the order of 207 kg_{CO2}/t [23]. As described in the method section, a reduction of 8 % is achieved when using plastic waste, which has an emission factor of 16 $kg_{CO2}/t_{plastic\ waste}$. So far, this value does not include emissions from the transport of the plastic waste. A comparison with the previous chapter on the emissions from logistics shows that for a reasonable transportation distance of up to a few hundred kilometers CO_2 emissions will be reduced when plastic waste substitutes bitumen.

Summarizing the findings presented here, and in the methods chapter, we can state the following key messages:

- With regard to waste collection and logistics
    - CO_2emissions from collection and sorting activities within the project´s activities are neglectable as those are carried out manually with no significant expendable materials used.
    - When using plastic waste for co-processing, the emissions of transportation between the MRF and cement plant make up a small percentage of the total CO_2 emissions only.
- With regard to co-processing in cement kilns
    - Here, the scope of the processes is very relevant. If the baseline scenario is to collect and burn plastic waste – substitution of fossil fuels in cement kilns can be presented as a CO_2 saving scenario. On the other hand, if the baseline scenario is to leave plastic waste uncollected in the environment, no major CO_2 saving can be stated as CO_2 emissions per unit energy are similar as those of conventional fuels used in cement production.
    - Up to this stage, it is not yet possible to quantify the CO_2 savings from using plastic waste.
- With regard to road construction
    - The usage of plastic waste in road construction as an end-of-life option should be closely considered. If, for instance, bitumen is replaced, CO_2 savings can be achieved in that scenario.

These first assessments clearly show that “CO_2 saving” as a stand-alone indicator is not sufficient to present the overall positive environmental impacts that come along with the implementation of a waste management system. From a CO_2 perspective, recycling of plastic waste can clearly be seen as the preferred option. Also, CO_2 savings can be achieved when the recycled material is used to substitute other plastic material. However, the real-life scenarios – particularly in the rural regions of India – are more complex, the infrastructure challenging, and the high amounts of LVP (MLP in particular) non-recyclable. Against this background, the Final Assessment Report will not only scope potential CO_2 savings but overall environmental and social impacts that come along with the implementation of a waste management system (see direct and indirect indicators in Table 2).

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