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The contribution of plastic recovery to resource efficiency and greenhouse gases (GHG) savings

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1. Consequential life cycle assessment (cLCA) of plastics recycling in Spain

1.1. Life cycle inventories

1.1.1. Raw materials [A] and virgin plastics production [B]

Data for life cycle inventory (LCI) of virgin plastic production are from Ecoinvent (Hischier, 2007) which are derived from datasets provided by Plastic Europe representing European Average production from 1999. Data is aggregated and take into account all materials inputs (i.e., electricity) needed from raw material extraction (i.e., oil) to virgin plastic production. Table B1 shows the virgin plastic considered and its respective LCI from ecoinvent.

Table B1: LCI of virgin plastic production from ecoinvent

Name	LCI data
Polyethylene, HDPE	Polyethylene, HDPE, granulate, at plant/RER
Polyethylene, LDPE,	Polyethylene, LDPE, granulate, at plant/RER
Polypropylene (PP)	Polypropylene, granulate, at plant/RER

Polyvinylchloride (PVC)	Polyvinylchloride, emulsion, polymerized, at plant / Polyvinylchloride suspension polymerized, at plant
Polystyrene (PS)	Polystyrene, general purpose, GPPS, at plant
Polyethylene terephthalate (PET)	Polyethylene terephthalate, granulate, amorphous, at plant/RER

1.1.2. Wood lumber manufacture [I] and wood production [J]

In the case of the LCI for wood lumber manufacture, we consider that the substituted would be wood. LCI data for the wood lumber production was review for (Astrup et al., 2009) and they used that data from Sathre (Sathre, 2007) for wood lumber production as substitute of virgin wood. Data for electricity consumption was, however, recalculated as only data on primary energy was available in Sathre (Sathre, 2007) as well as the amount of fuel oil (Astrup et al., 2009).

1.1.3. Recycling [F]

The mechanical recycling process requires the waste plastic to be shredded and extruded to form recycled granulate ready for use in new products (Shonfield, 2008). Electricity consumption for recycling of different plastic scrap types have been review in (Shonfield, 2008; Astrup et al., 2010; Chen et al., 2011 and Schmidt et al., 2012) ranging from 270 kWh t^{-1} to 330 kWh t^{-1} for Europe and an average of 229 kWh t^{-1} has been used in this study; and 575 kWh t^{-1} for China. LCI data of the recycling process was considered similar for the recycled plastic lumber production.

The recycling processes in China and Europe were also modeled and are included in the calculations also with the electricity marginal mixes considered for each of them. Detail explanation of the marginal electricity mixes are given in section 1.1.7.

In addition, a material recovery efficiency of 85% was used, implying that 15% of the starting material is lost as impurities. The following treatments were included: in China, such losses are sent to landfills; in Spain, such losses are sent to landfills; and in Europe, such losses are incinerated. We considered that the incineration treatment plants also produce electricity and heat, and therefore, the avoided electricity and heat are also taken into account (see section 1.1.5) from the quantifications.

1.1.4. Collection, sorting and international transport [E]

Data regarding the collection and transport to different facilities in Spain were estimated based on the data from previous Spanish works (Rives et al., 2010; Retorna, 2011) and are shown in Table B2. The transport distances from Spain to China were calculated based on a previous work (Itene, 2008) while the transport distance to Europe was assumed of 5,000 km (average). All of the distances were calculated using the EcoTransIT tool (EcoTransIT, 2012) and LCI data for each type of transport was from ecoinvent (Spielmann et al.,2007). Data regarding the electricity and diesel consumption in sorting plants were provided by waste managers in Spain (not shown).

Table B2: Inventories for the collection and transport of 1 ton of waste plastic in Spain

	Road Transport (km)	**Type of transport**
Collection (SP)	60	Road
To sorting plants (SP)	300	Road
To port (SP)	300	Road
Waste from sorting plant to landfill (SP)	50	Road
Waste from recycling plant to final treatment (SP/CN/EU)	50/100/50	Road
To recycling plant China (CN)	16,500 (300)	Sea (Road)
To recycling plant Europe (average) (EU)	5000	Rail

1.1.5. Energy recovery [G]

The incineration with energy recovery of plastic waste as another end of life treatment is outside of the scope of the study but the processed waste from the sorting plants and recycling facilities undergoes to energy treatment or landfill. In this paper we assumed that the processed plastic waste in Europe undergo to energy recovery. LCI data was obtained from ecoinvent (Doka, 2003a). However, the ecoinvent activities do not include energy recovery. Therefore, this is added to the relevant ecoinvent activities. In Europe, it is considered that the energy recovery rates are 71% and 14% for electricity and heat, respectively, according to (Schmidt et al., 2012).

1.1.6. Landfill [K]

LCI data of waste from sorting and recycling facilities to landfill is based on ecoinvent data (Doka, 2003b).

1.1.7. Marginal electricity inventory

The marginal electricity production used in this study was modeled following previous recommendations by Schmidt et al. (2011) and (Schmidt and Thrane, 2009). The marginal electricity was calculated differentially by country (or region) for all of the processes involved in this study; Spain, China and Europe. For Spain, we used data and projections from the Ministry of Industry, Energy and Tourism (Minetur, 2011), in which it was established that the structure of electricity generation in Spain will continue to evolve over the forecast period in the same way as it has done in recent years, with a reduction in the weight of oil and coal in the generation mix, a slight increase in the natural gas weight and greater growth of renewable energy and hydroelectric pumping (Minetur, 2011). For Europe and China, we used data and projections from (Schmidt and Thrane, 2009).

Besides, for the sensitivity assessment we considered the electricity mixes from 2011 obtained from the Energy International Agency (EIA, 2013). Table B3 summarizes the electricity mixes for each country or region.

Table B3: Marginal electricity mixes considered for each country and the average electricity mixes from 2011 used for the sensitivity assessment

	Spain		**Europe**		**China**	
	Marginal electricity production (%)	**Sensitivity assessment MIX 2011 (%)**	**Marginal electricity production (%)**	**Sensitivity assessment MIX 2011 (%)**	**Marginal electricity production (%)**	**Sensitivity assessment MIX 2011 (%)**
Hard Coal	0	15	28	27	82	79
Oil	0	5	0	2	0	0
Natural Gas	94	29	46	21	2	2
Biomass	0	2	0	5	0	1
Nuclear	0	20	0	28	5	2
Hydropower	6	11	29	10	11	15
Wind	0	15	0	5	0	1
Solar PV	0	3	0	1	0	0

2. Results from sensitivity assessment

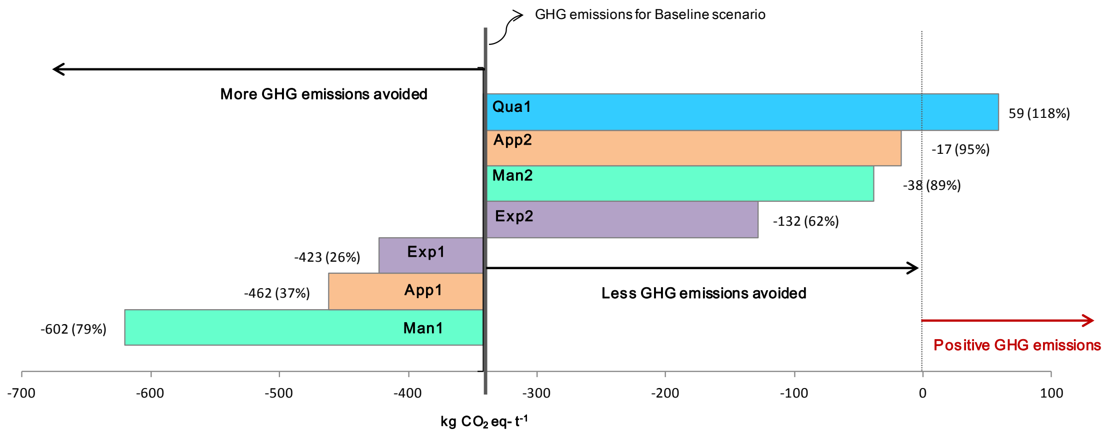

Figure B1: GHG emissions for the alternative scenarios (kg CO_2 eq. t^{-1}) for the sensitivity assessment

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