# LCA applied to the assessment of Waste Management Systems (Research Seminar ESCI-UPF)

Alba Bala Online, 04-05-2021





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## The origin of the problem...

- Waste generation is inherent to human activities.
- In the Middle Ages the accumulation of food and waste in cities caused serious health problems.
- The "first waste management practices" are developed.



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## The aggravation of the problem...

- With the arrival of industrialization, the following occurs: higher volume of waste.
- The 20th century coincides with:
  - the development of artificial materials derived mainly from petroleum and
  - the growth of the throwaway culture.
- reduction of natural resources.

HANGE





- Landfill becomes the most widely used management option (sometimes combined with incineration).

• All these factors lead to a problem added to the generation and volume of waste: the progressive



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## LCA applied to Waste Management Systems

- of WMS.
- making and planning in Europe.
- **system**, collecting all the processes and associated environmental impacts.
- **impact categories** (global warming potential, acidification, eutrophication...)



The LCA began its development in 1980 and at the end of the 90s it started to be used for the analysis

LCA has been gaining acceptance in recent years as a tool to aid waste management policy decision

The LCA helps to broaden the perspective of the analysis and have a more complete view of the entire

This approach can avoid the undesirable shift of environmental loads between different stages of the waste management system, geographic areas, environmental compartments (air, land and water) or



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System Boundaries

Life cycle stages

1. Raw material extraction

2. Manufacture

3. Distribution

4. Use

5. Waste management

Source: Hauschild & Barlaz, 2011. Based on White et al., 1995. Reprinted with permission from Integrated Solid Waste Management – A life Cycle Inventory 2 E by F. McDougal, P. White, M. Franke and P. Hindle, 2001. Wiley.







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### **ZERO BURCEN APPROACH:**

We only count the environmental impact from when the products become waste







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### Functional Unit

**PRODUCTS** 

The functional unit is **defined by the** outputs of the system (for instance) the amount of goods produced by an industry)

WASTE MANAGEMENT **SYSTEMS** 

The service function provided by the system is to collect, treat and dispose a certain amount of waste being, consequently, related to the input of the system.



### Aspects to be considered:

- Amount of waste to be managed
- Composition of waste
- Duration of the system or the service upon which the environmental impacts will be quantified
- Quality of the management system (emission) \_\_\_\_\_ boundaries, requirements for the recovered materials...)



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Approach





Source: Bjarnadóttir et al., 2002.



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### • Time perspective and landfills

In landfills, we do not have instantaneous emissions like in an incineration plant.

We have to integrate all the emissions associated to our FU (usually a 100 years horizon is considered)









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Open-loop recycling







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### Life Project: 36 months (2010-2013)

### **Objectives:**

 To create a user-friendly and flexible tool for easily obtaining LCA results of packaging waste management alternatives.

 To compile a specific database and parametrized models on waste treatment and recycling technologies for Spain and Portugal.





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Giving Packaging a New Life

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UAB de Barcelona

PhD

- Product specific models for:
  - Incineration plants
  - Landfills \_
  - Sorting plants -
- New method to calculate EoL credits of materials
- New predictive model for collection

### **SUSTAINABILITY ASSESSMENT**

**Environmental** Economic Social

**ARIADNA** Project Adapted to the Basque Country







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PhD

Product specific models for:

- Incineration plants
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**ARIADNA** Project Adapted to the Basque Country







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YOUTHON'S DEPARTON CODY

Int J Life Cycle Assess (2015) 20:645-654 DOI 10.1007/s11367-015-0861-3

LCA OF WASTE MANAGEMENT SYSTEMS

### Introducing a new method for calculating the environmental credits of end-of-life material recovery in attributional LCA

Alba Bala Gala · Marco Raugei · Pere Fullana-i-Palmer

SC 111 100 T aluminium 125 T paper 150 T glass 120 T plastic

### Non-comparable systems



- Most LCA of WMS assume a 1:1 substitution factor.
- Some authors have analysed the  $\bullet$ influence of other factors (paper and plastic) and observed that they can have an important effect on the results.



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## Environmental credit = x \* REC + (1 - x) \* Q \* VIR

Where:

- is the proportion of recycled material in the average X market mix
- is the proportion of virgin material in the average (1-x)market mix
- is the quality factor of recycled material vs. virgin Q material ( $Q \leq 1$ )
- is the environmental load of the recycling process REC (1 t of recycled material in output)
- is the environmental load of the production process VIR of the virgin material (1 t in output).



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Material	% Virgin	% Recycled	Source
Aluminium*	63	37	Calculated from EAA 2011
Steel	50	50	EUROFER 2014
Glass	55	45	Roldán and Pino 2012
Cardboard	16	84	Calculated from CEPI 2010
Paper	71	29	Calculated from CEPI 2010
Beverage cardboard	57	43	Calculated from CEPI 2010
Plastics**	**	**	

**Table 1** Average European market mixes for different materials

\*For the packaging sector, these percentages move to 25 % of virgin and 75 % of recycled

\*\*The percentage of recycled plastic is difficult to quantify



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### **Putting the formula into practice:**





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Situation (a) (illustrated by the case of aluminium), in which the calculation of the credit mainly depends on the market mix. In this case, the impact of virgin production (VIR) is about 10 times higher than that of the recycling process (REC/VIR  $\approx 0.1$ ). At the same time, the quality factor is virtually equivalent to 1 (the same also applies to many other metals and glass). Thus, from a pragmatic point of view, in these cases, using the market mix alone is considered a reasonably good proxy, and the credit closely matches that of the simple weighted average of the mix itself.

Environmental credit = x \* REC + (1 - x) \* \* \* VIR



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### **Putting the formula into practice:**



 Impact of primary production •••••• Impact of mix production Avoided impact (considering Q) factor)



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Situation (b) (illustrated by the case of high-density polyethylene). In this case, the impact of the recycling process is still lower than that of virgin production, but the difference is not so large (REC/VIR  $\approx 0.2$ ). Additionally, the credit is strongly influenced by the application of the quality factor ( $Q \approx 0.75$ , as obtained through laboratory tests, to be published shortly). Thus, the lower the quality of the recovered material, the less credit one has. The result is that the credit line lies lower than that indicating the production impact of one unit of material according to the market mix. This is typically the case for most other plastics too.

Environmental credit = x \* REC + (1 - x) \* Q \* VIR



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### **Putting the formula into practice:**



 Impact of primary production ······ Impact of mix production Avoided impact (considering Q factor)



Situation (c) (illustrated by the case of paper). This situation merits special attention due to the fact that the line indicating the credit ends up having a positive slope, instead of the normal negative one seen in all other cases. This counterintuitive result is due to the fact that the Q factor is actually *lower* than the ratio of the impact of recycling to that of virgin production  $(Q \approx 0.83 \text{ and REC/VIR} \approx 0.9)$ . As a consequence, the credit actually *increases* as the recycling replaces more and more secondary material (since the quality reduction only affects the replacement of the virgin material). This indicates that, because of the inevitable quality loss inherent in the recycling process, recycling waste paper is actually more beneficial (in terms of credits) if the output can be used to contribute to a wellestablished mix of already mainly secondary paper products (e.g. in the packaging sector<sup>1</sup>) than if it were employed to provide its inevitably low-quality fibre to a production mix still dominated by virgin paper (e.g. in the publishing sector).



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- Article 1
- <sup>2</sup> Assessing the environmental performance of municipal solid waste collection: a new predictive LCA model
- Alba Bala 1\*, Marco Raugei 2, Carlos Afonso Texeira 3, Alberto Fernández 4, Francisco Pan-Montojo 5, and Pere Fullana-i-Palmer 1,
  - There are specific software's for • performing LCA of Waste Management Systems
  - None of them pay special attention ulletto the collection and transport stage.



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Table 1. The most widely known, used and complete waste LCA models

Software	Country	Launch time	Reference		
ORWARE (a)	Sweden	1997	[35,36]		
MSWI	Germany	1998	[37]		
EPIC/CSR	CA	1999	[38-40]		
MSW-DTS	USA	1999	[41,42]		
WIZARD	UK, FR, NZ	1999	[43]		
IWM-2 <sup>(b)</sup>	United Kingdom	2001	[44]		
SSWMSS	Japan	2004	[45,46]		
LCA IWM (c)	European Union	2005	[47-49]		
WRATE (d)	United Kingdom	2007	[50,51]		
EASEWASTE	Denmark	2008-2009	[52]		
EASETECH	Denmark	2013	[53]		
SWOLF	USA	2014	[54]		





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In those software, there are three levels of complexity:

- $\bullet$ emission factors.
- ulletwaste collected or the km travelled. Then corresponding emission factors are also applied.
- Level 3: In which distances or time spent in the collection are not directly entered by the user, but consumption factors.

 $\rightarrow$  2 and 3 assume a direct correlation between the distance travelled, waste collected or time spent and diesel consumption.



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**Level 1:** Require that the user input the total amount of fuel consumed directly, and then apply fixed

Level 2: Require the input of fuel consumption (or efficiency rates) (ex. L/ton or L/km) and the input of calculated by means of a set of operational parameters like travel speed, distances between different parts of the route or time spent in different operations. Such km or hours are then multiplied by fixed





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- We developed a new model and ulletcompared it with Level 3 software packages and real data.
- Experimental Data: 14 kerbside collection routes in Portugal for different fractions:
  - MSW (municipal solid waste)
  - LPW (light packaging waste)
  - P (paper and cardboard)
  - G (Glass)





Figure 1. Research steps.



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C MSW-DS ORWARE Experimental Ecolovent



### **Results:**

- Graphs are expressed in a base-2 log scale. ullet
- None of the models match experimental data; only ulletin the cases which the characteristics of experimental routes happened to coincide with those with the calibration routes on which average rates are based perform better.
- In some cases, we have un underestimation of the ulletcollection stage by a factor of 4!



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### Iterative model with limiting factors:

- 1) Maximum number of containers per collection route
- 2) Maximum volume or weight capacity of the truck
- 3) Maximum duration of the working day



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**Table 4.** Main operational data included in the model to calculate model key parameters

Input Data	Default parameters and intermediate calculations						
$W_T$ : total amount of waste collected [kg]	$\beta j$ : consumption truck correction factor [-]						
dens: waste density [kg/m <sup>3</sup> ]	<i>Pl:</i> maximum payload capacity of the truck [kg <sub>load</sub> ]						
Freq: collection frequency [year-1]	$A_j$ : diesel consumption of the empty truck, depending						
C: number of containers [-]	on the type of road [kg <sub>diesel</sub> /km]						
$V_c$ : average volume per container [m <sup>3</sup> /C]	$B_j$ : diesel consumption of the full truck, depending on						
$V_t$ : volume capacity of the truck [m <sup>3</sup> /truck]	the type of road [kg <sub>diese</sub> l/km]						
$D_I$ : Distance between the parking lot and the collection	$F_{comp}$ : diesel consumption factor while the truck is						
route <sup>(a)</sup> [km]	lifting containers and compacting waste [kg <sub>diesel</sub> /h]						
$D_3$ : Distance from the collection area <sup>(a)</sup> to the unloading	$W_{box}$ : weight of the box truck [kg]						
site [km]	<i>Fill<sub>c</sub>:</i> average container fill ratio [%]						
$D_c$ : Distance in between individual containers [km/C]	$cr_t$ : compaction ratio of the truck [-]						
$D_4$ : Distance between the unloading site and the parking	ef: collection efficiency in number of containers						
lot [km]	collected per hour [C/ h]						
$T_T$ : Duration of the working day [h]	S <sub>col</sub> : average speed while collecting [km/h]						
Output Data	Stransp: average speed while transporting [km/h]						
$\alpha_j$ : share of km travelled in each type of road [-]	$T_{comp}$ : time spent loading and compacting waste [h]						
$U_r$ : utilization (fill) ratio of the truck by mass [-]	Tunload: time spent unloading waste [h]						
$D_T$ : distance of one full trip of the waste collection truck	$T_{luch}$ : time for lunch brake [h]						
[km]	$T_{transp}$ : total time spent while transporting [h]						
	$T_{col}$ : time spent collecting [h]						
	D <sub>2</sub> : Total distance spent while collecting waste						
	(effective collection distance) [km]						
	N: number of trips per truck [-]						



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aste fraction llected lass	Route	Experimental	Relative deviation from experimental data								
	Code	(L/t)	FENIX	ORWARE	MSW-DST	Ecoinvent					
	G1	9.1	-0.34	0.54	-0.04	0.70					
	<b>G</b> 2	6.1	0.20	0.92	0.85	1.25					
SW	MSW1	12.2	0.44	-0.19	-0.69	-0.26					
	MSW2	10.0	-0.11	0.46	-0.55	0.07					
	MSW3	11.8	0.63	0.06	-0.62	-0.34					
ght Packaging											
aste	LP1	25.6	-0.11	-0.48	0.57	-0.38					
	LP2	12.7	-0.13	-0.09	0.48	0.22					
	LP3	26.6	-0.25	-0.66	-0.01	-0.58					
	LP4	25.3	0.26	-0.73	-0.27	-0.69					
per & Cardboard	P1	11.2	-0.01	-0.17	0.20	-0.19					
	<b>P</b> 2	6.2	0.12	0.48	0.36	0.80					
	P3	18.9	-0.11	-0.38	-0.02	-0.26					
	<b>P</b> 4	14.4	0.19	-0.45	-0.31	-0.42					
	<b>P</b> 5	11.7	0.65	-0.27	-0.48	-0.41					
um of the squared o	leviations		1.41	3.27	3.01	4.35					

Waste fraction	Route	Experimental	Relative deviation from experimental data							
collected	Code	(L/t)	FENIX	ORWARE	MSW-DST	Ecoinvent				
Glass	G1	9.1	-0.34	0.54	-0.04	0.70				
	<b>G</b> 2	6.1	0.20	0.92	0.85	1.25				
MSW	MSW1	12.2	0.44	-0.19	-0.69	-0.26				
	MSW2	10.0	-0.11	0.46	-0.55	0.07				
	MSW3	11.8	0.63	0.06	-0.62	-0.34				
Light Packaging										
Waste	LP1	25.6	-0.11	-0.48	0.57	-0.38				
	LP2	12.7	-0.13	-0.09	0.48	0.22				
	LP3	26.6	-0.25	-0.66	-0.01	-0.58				
	LP4	25.3	0.26	-0.73	-0.27	-0.69				
Paper & Cardboard	P1	11.2	-0.01	-0.17	0.20	-0.19				
	<b>P</b> 2	6.2	0.12	0.48	0.36	0.80				
	P3	18.9	-0.11	-0.38	-0.02	-0.26				
	P4	14.4	0.19	-0.45	-0.31	-0.42				
	P5	11.7	0.65	-0.27	-0.48	-0.41				
Sum of the squared	deviations		1.41	3.27	3.01	4.35				



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Table 5. Comparison of FENIX results with experimental and existing models

### It performs better



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Table 6. Effects of selected operational parameters of the route on the waste collection performance

INPUT DATA										CALCU	LATED	DATA	1						
	Waste [t]	Working day[h]	Yearly Freq.	N. cont	container volume [m <sup>3</sup> ]	truck volume [m <sup>9</sup> ]	Dist parking-fist cont	Dist end coll-unloading	Dist unloading point -parking	Dist between collection areas	Performance [n.cont/h]	[kg diesel/(t.km)]	Annual km travelled	km/trip	líyear	TA IA			
Baseline	92.2	8	55	449	0.25	22	1.7	10.2	10.7	0	41.2	0.86	3462	31	2928.48	31.76			
1	92.2	8	55	269	0.25	22	1.7	10.2	10.7	0	41.2	0.49	2184	40	2171,13	23.55			
2	92.2	8	55	494	0.25	22	1.7	10.2	10.7	0	41.2	1.00	3462	31	3419.55	37.09			
3	92.2	8	70	449	0.25	22	1.7	10.2	10.7	0	41.2	1.20	4406	31	4123.59	44.72			
4	92.2	8	110	449	0.25	22	1.7	10.2	10.7	0	41.2	1.88	6923	31	6435.03	69.79			
5	92.2	6	55	449	0.25	22	1.7	10.2	10.7	0	41.2	1.20	4739	29	3853.33	41.79			
6	92.2	4	55	449	0.25	22	1.7	10.2	10.7	0	41.2	1.44	6016	27	4280.64	46.43			
7	92.2	8	55	449	0.25	22	3.4	20,4	21.4	25	39.3	0.67	7257	66	4915.81	53.32			
S	92.2	8	55	449	0.25	22	3.4	20.4	21.4	50	37.5	0.64	8602	78	5469.50	59.32			

Note: Changes with respect to the baseline scenario are marked in bold.



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### CONCLUSIONS

- $\bullet$ collection stage need to be uses warily.
- If the aim of the project is to improve the collection stage, real data should be used adjusting the  $\bullet$ presented in the paper.
- $\bullet$ neglected in LCA models or studies).



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Fixed consumption rates included in some LCA tools or database for WMS to calculate the impact of the

parameters of the collection route as much as possible, or conversely, use predictive models as the one

The duration of the working time has been identified as an important issue to take into account (usually





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## **ARIADNA Project**

The aim of the ARIADNA project was to analyse the sustainability (environmental, economic and social) of the implementation, in Spain and in Catalonia, of a mandatory DRS versus the current situation

**SYSTEM A:** current situation of packaging waste management in Spain 2014, though Ecoembes and Ecovidrio Green Dot Systems.





**SYSTEM B:** hypothetical introduction of a DRS in Spain in 2014 coexisting with a GDS for the rest of packaging waste, considering a 90% return rate without considering a learning curve.







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56%

43%







## **ARIADNA Project**





A step back for the environment

Their processes are more polluting and would be detrimental to Key Factors such as Global Warming Potential, Acidification or Eutrophication

It is way more expensive than the current system. I would imply an additional cost of 290 million euros. That is, each Catalan family would pay 100 euros more per year for the implementation of the SDDR





### Greater cost for society

More dedication of time and space for citizens

A bigger effort for citizens, as well as a greater degree of discomfort in managing this type of waste in their home environment





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## **ARIADNA Project**

The aim of the ARIADNA project was to analyse the sustainability (environmental, economic and social) of the implementation, in Spain and in Catalonia, of a mandatory DRS versus the current situation



Science of The Total Environment Volume 721, 15 June 2020, 137744





Environmental impact assessment of the implementation of a Deposit-Refund System for packaging waste in Spain: A solution or an additional problem?

Cátedra UNESCO de Science of The Total Environment Ciclo de Vida y Cambio Climático Volume 702, 1 February 2020, 134603 CO de Environmental assessment of the food packaging waste management system in Spain: "Estudio de sostenibilidad sobre la introducción de ul Understanding the present to improve the SDDR obligatorio para envases en España viental, social y económico future A. Bala ª, J. Laso <sup>b</sup>, R. Abejón <sup>b</sup>, M. Margallo <sup>b</sup>, P. Fullana-i-Palmer <sup>a</sup>, R. Aldaco <sup>b</sup> 🙁 🖾 CI upt

R. Abejón <sup>b</sup>, J. Laso <sup>b</sup>, M. Margallo <sup>b</sup>, R. Aldaco <sup>b</sup> R 🖾, G. Blanca-Alcubilla <sup>a</sup>, A. Bala <sup>a</sup>, P. Fullana-i-Palmer <sup>a</sup>



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https://www.esci.upf.edu/es/catedra-unesco-de-ciclo-de-viday-cambio-climtico/estudio-ariadna



## **ARIADNA Project – Basque Country adaptation**

### **CHANGES IN RELATION TO THE ORIGINAL ARIADNA MODEL**

- Changing the conditions of the DRS (best case study). ullet
- Only through reverse and compacting vending machines (RVM). ullet
- Including public RVM. ullet
- Reverse logistic in all cases. lacksquare

### CONCLUSIONS

- DRS performs better than the current system.
- For GWP the balance is negative IN BOTH CASES (we are emitting more than crediting).
- A change in the policy, looking for more closer recyclers could improve GWP emissions.
- Burning plastics is not beneficial for the environment, we are polluting more than crediting.





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# Many thanks!

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