LCA applied to the assessment of Waste Management Systems

(Research Seminar ESCI-UPF)

Alba Bala

Online, 04-05-2021

UNESCO CHAIR IN LIFE CYCLE AND CLIMATE CHANGE
UNESCO CHAIR IN LIFE CYCLE AND CLIMATE CHANGE

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.

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

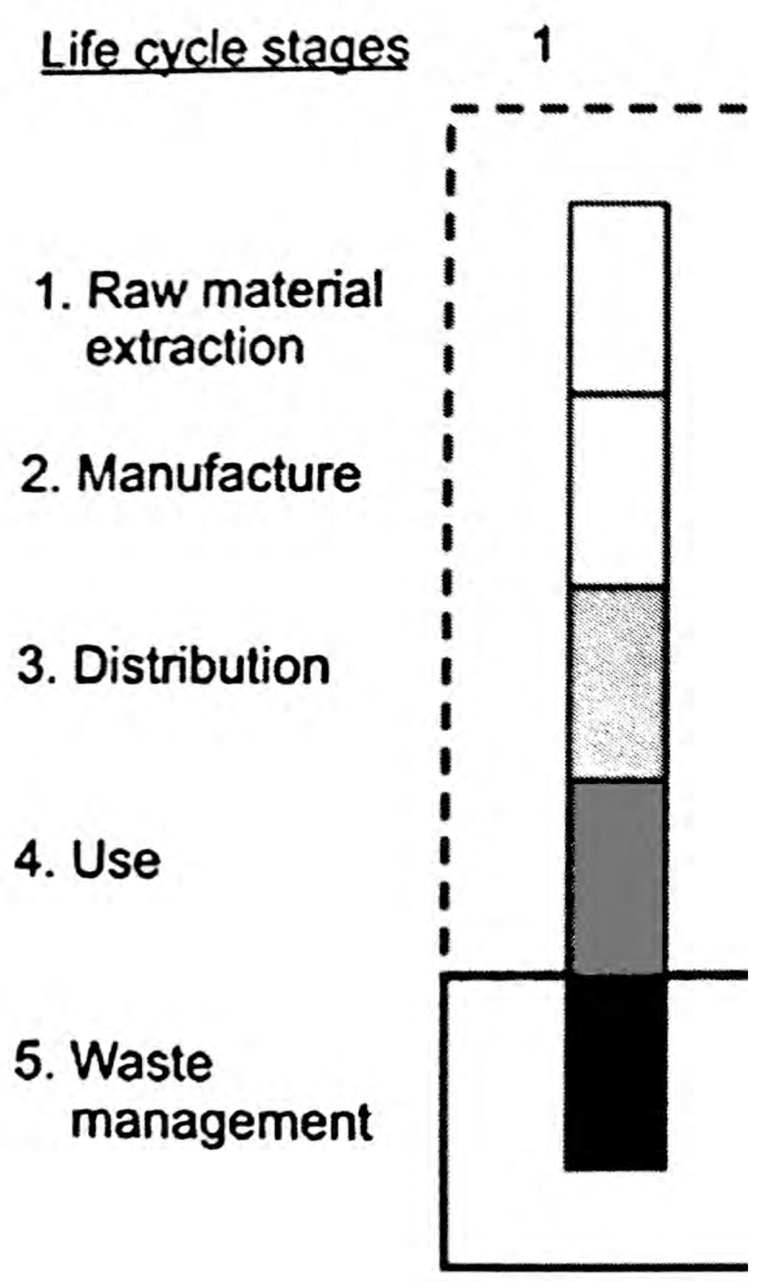
- All these factors lead to a **problem added** to the generation and volume of waste: **the progressive reduction of natural resources**.

LCA applied to Waste Management Systems

- The **LCA** began its development in 1980 and **at the end of the 90s it started to be used for the analysis of WMS.**
- LCA has been gaining acceptance in recent years as a **tool to aid waste management policy decision making and planning in Europe**.
- The LCA helps to broaden the perspective of the analysis and have a more **complete view of the entire system**, collecting all the processes and associated environmental impacts.
- 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 impact categories** (global warming potential, acidification, eutrophication. ..)

Differences between LCA of products and LCA of waste

- **System Boundaries**



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.

UNESCO CHAIR IN LIFE CYCLE AND CLIMATE CHANGE

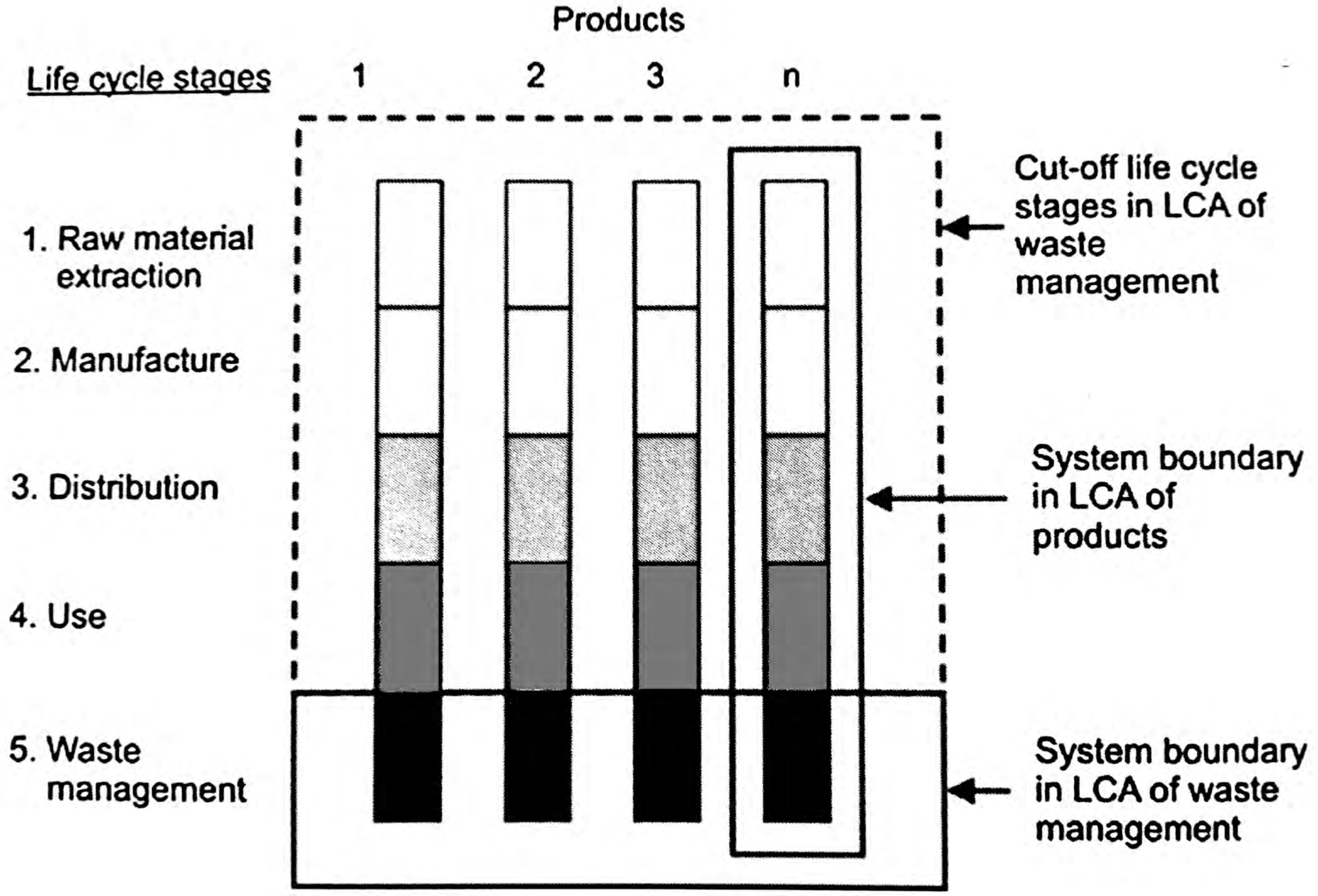
UNESCO CHAIR IN LIFE CYCLE AND CLIMATE CHANGE

Differences between LCA of products and LCA of waste

- **System Boundaries**

ZERO BURCEN APPROACH:

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



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.

Differences between LCA of products and LCA of waste

- **Functional Unit**

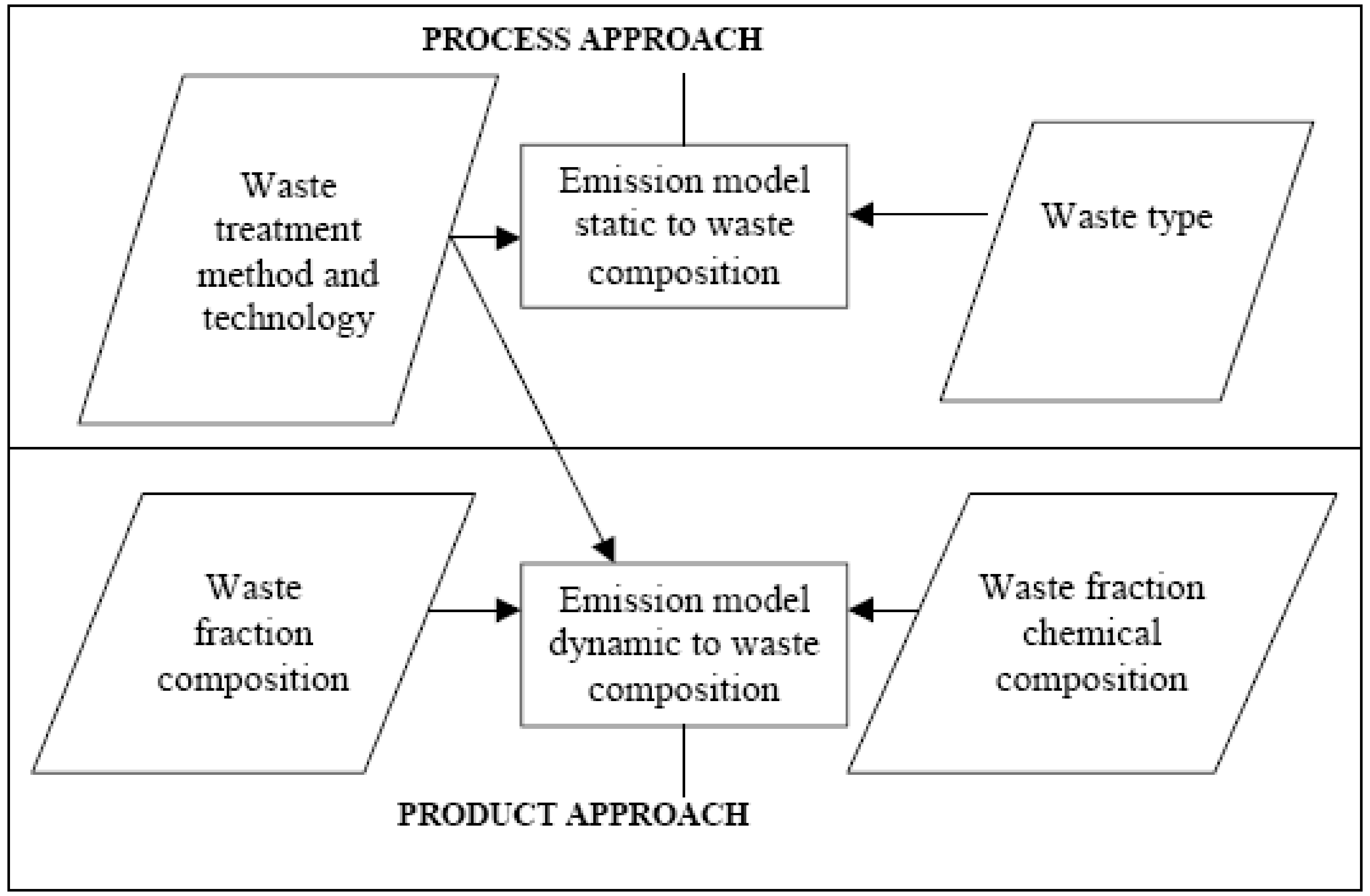
PRODUCTS	The functional unit is **defined by the outputs of the system** (for instance the amount of goods produced by an industry)
WASTE MANAGEMENT SYSTEMS	**The service function** provided by the system is to collect, treat and dispose a certain amount of waste being, consequently, **related to the 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...)

Differences between LCA of products and LCA of waste

- **Approach**



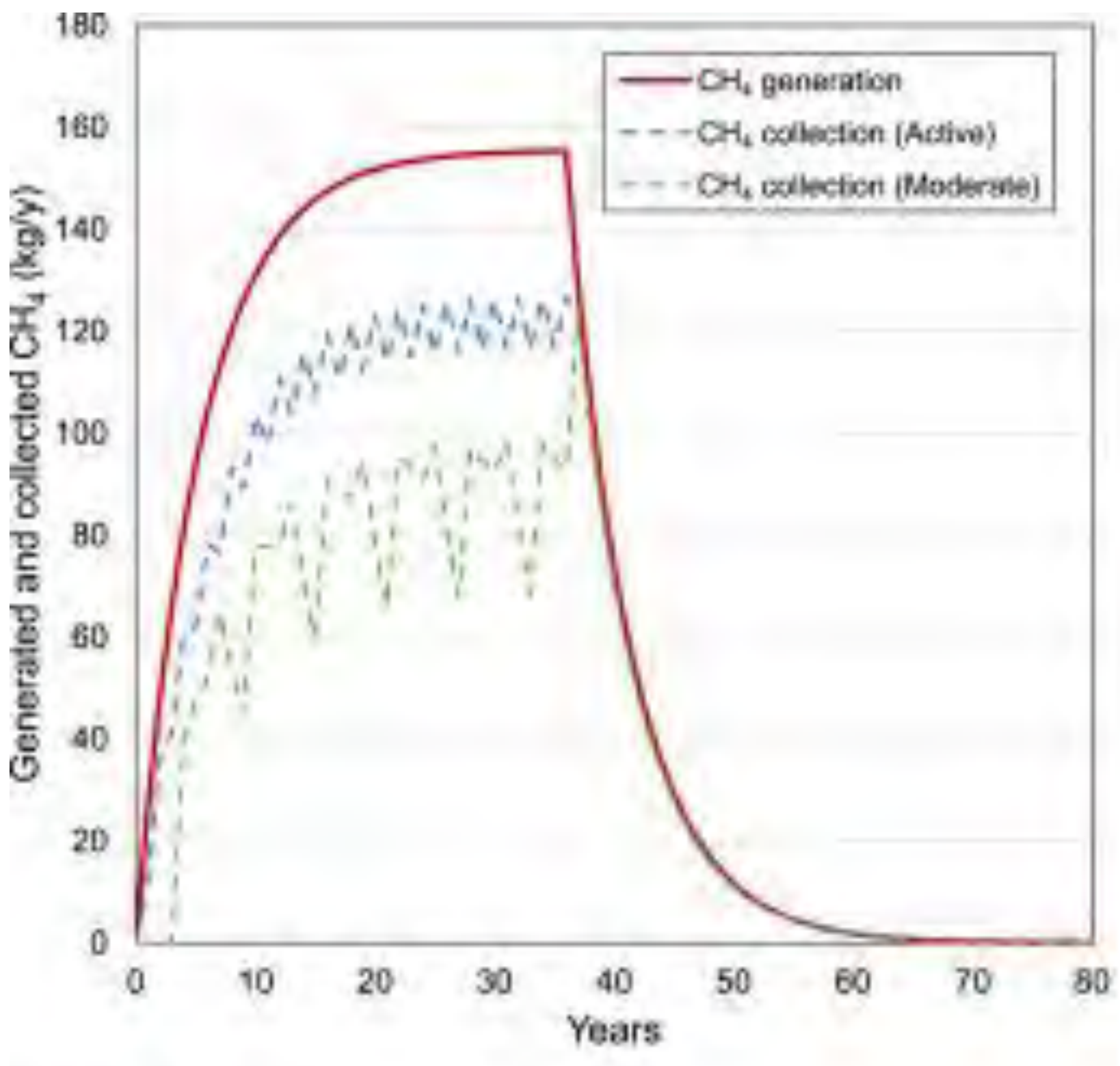
Source: Bjarnadóttir et al., 2002.

Differences between LCA of products and LCA of waste

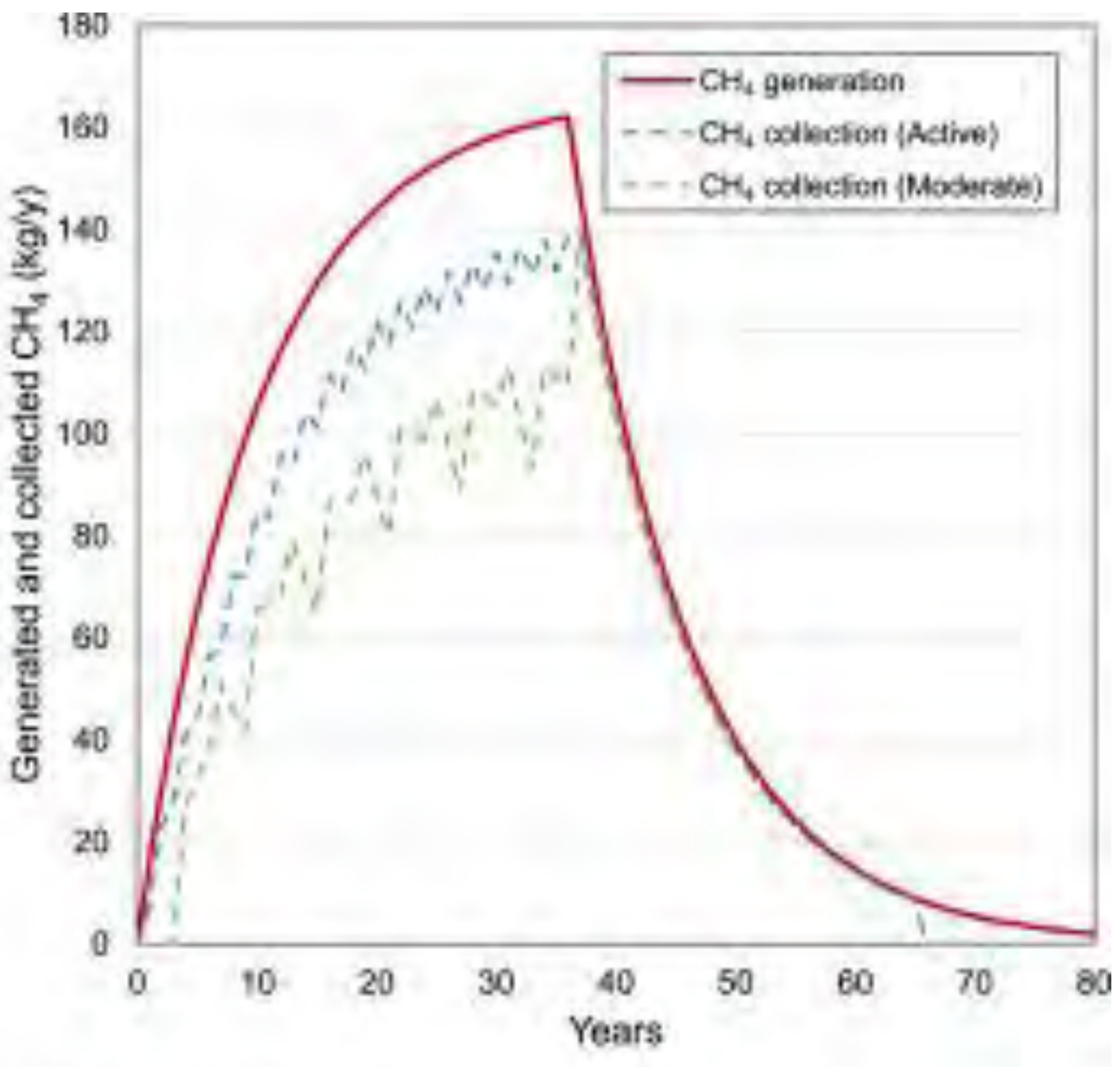
- **Time perspective and landfills**

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)



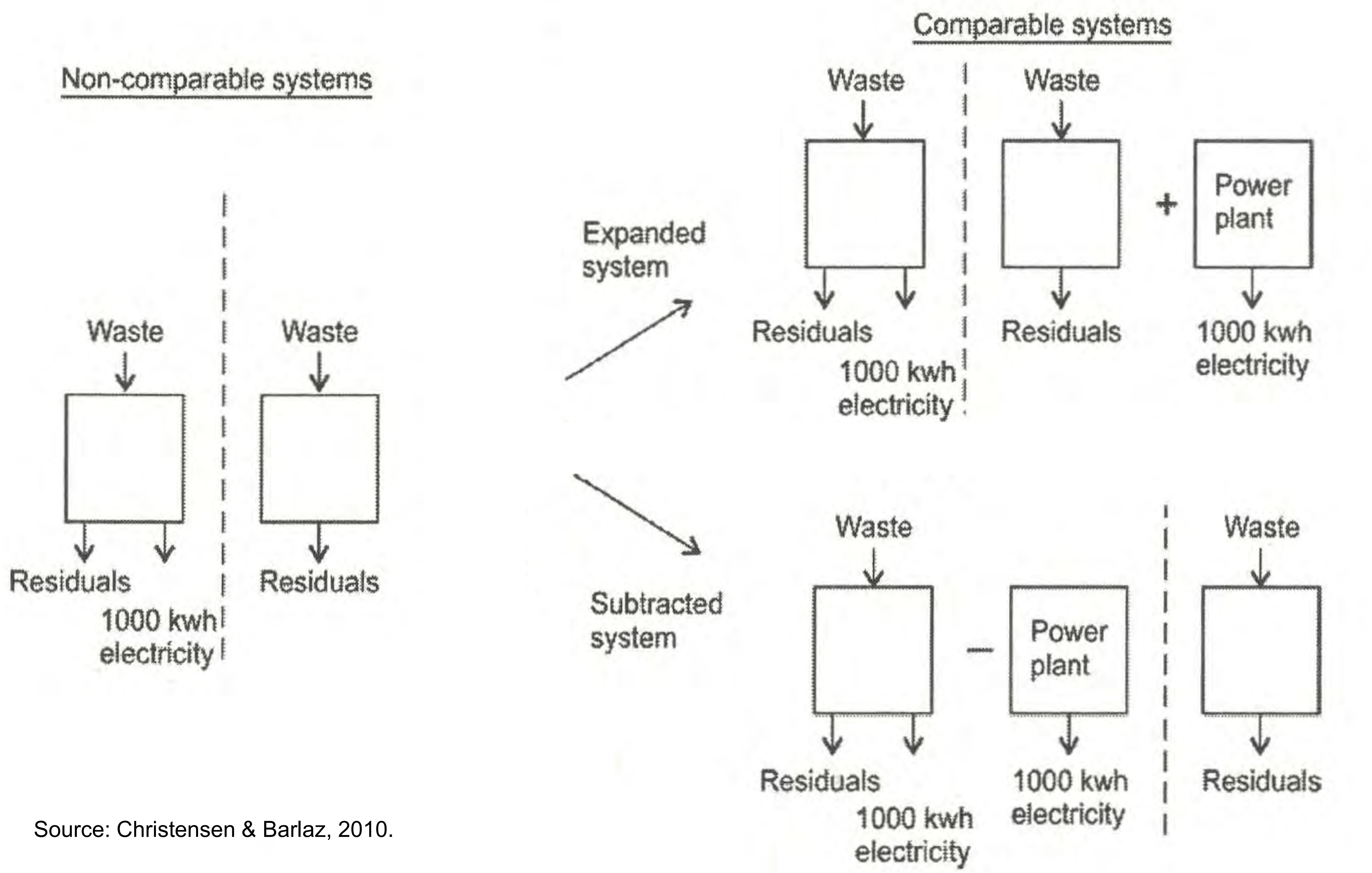
a) Food waste



b) Yard trimmings

Differences between LCA of products and LCA of waste

- **Open-loop recycling**



Source: Christensen & Barlaz, 2010.

EVOLUTION OF THE RESEARCH LINE

Financed by:

FENIX
Giving Packaging a New Life

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.

Coordinator

ESCI upf. International Business

Partners

ECOEMBES

sociedade pontoverde

PE INTERNATIONAL
EXPERTS IN SUSTAINABILITY

UNESCO CHAIR IN **LIFE CYCLE AND CLIMATE CHANGE**

ESCI upf. School of International Studies

UNESCO CHAIR IN LIFE CYCLE AND CLIMATE CHANGE

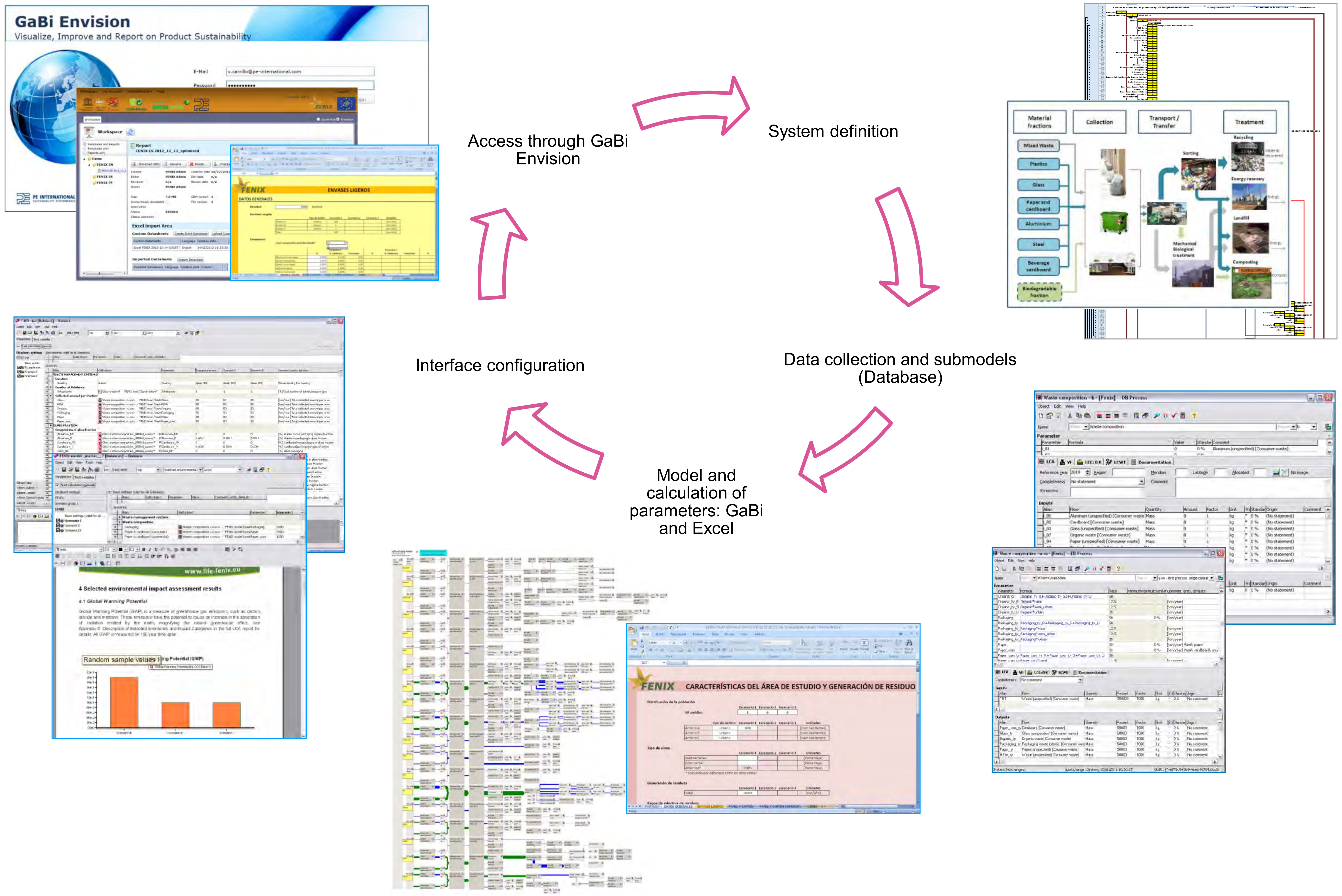
UNESCO CHAIR IN LIFE CYCLE AND CLIMATE CHANGE

EVOLUTION OF THE RESEARCH LINE

Financed by:

Life

FENIX
Giving Packaging a New Life



EVOLUTION OF THE RESEARCH LINE

Financed by: Life

FENIX
Giving Packaging a New Life

- Product specific models for:
  - Incineration plants
  - Landfills
  - Sorting plants

UAB Universitat Autònoma de Barcelona

PhD

- New method to calculate EoL credits of materials
- New predictive model for collection

ENVIRONMENTAL ASESSMENT

FENIX Tool
(Waste Management Environmental Assessment Tool and Database for Spain and Portugal)

CO2 Balance of Ecoembes (2015-2020)

Development of **simplified tools** to calculate the environmental impact of **prevention measures**

ARIADNA Project (DRS vs. Current system) **Spain and Catalonia**

ARIADNA Project Adapted to the Basque Country

SUSTAINABILITY ASSESSMENT

Environmental
Economic
Social

UNESCO CHAIR IN LIFE CYCLE AND CLIMATE CHANGE
ESCI upf School of International Studies

EVOLUTION OF THE RESEARCH LINE

Financed by: Life

FENIX Giving Packaging a New Life

UAB Universitat Autònoma 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

FENIX Tool
(Waste Management Environmental Assessment Tool and Database for Spain and Portugal)

ARIADNA Project
(DRS vs. Current system)
Spain and Catalonia

ARIADNA Project Adapted to the Basque Country

CO2 Balance of Ecoembes
(2015-2020)

Development of **simplified tools** to calculate the environmental impact of **prevention measures**

New approach for credits calculation

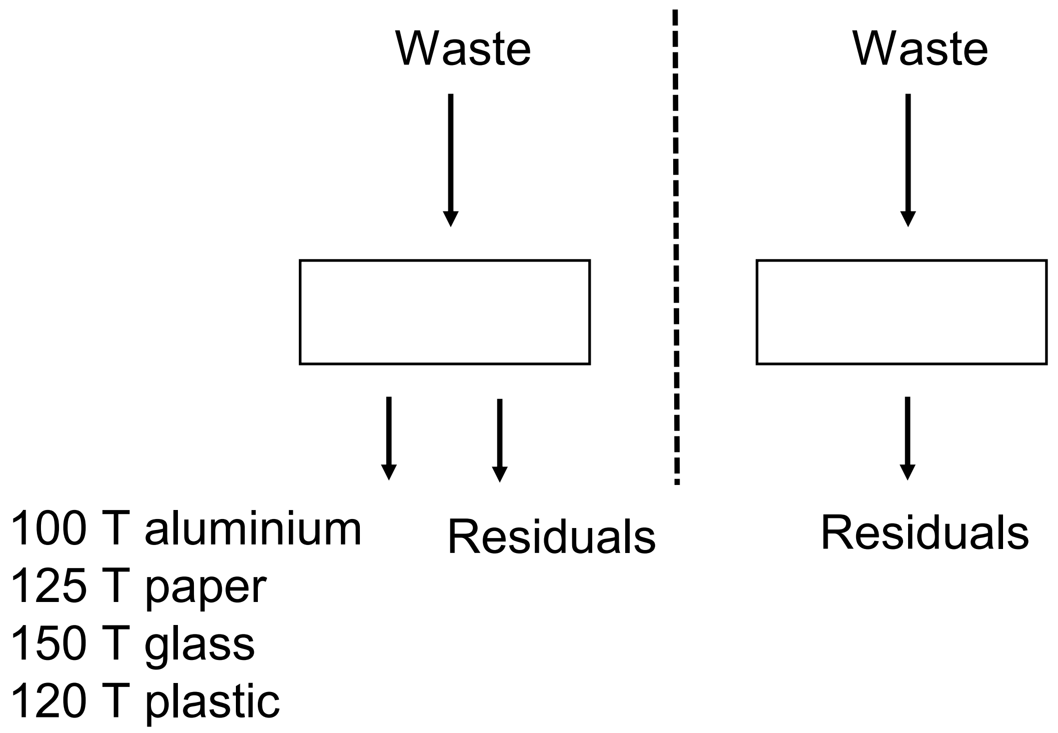
Int J Life Cycle Assess (2015) 20:645–654
DOI 10.1007/s11367-015-0861-3

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

Non-comparable systems



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

New approach for credits calculation

$$\text{Environmental credit} = x * REC + (1 - x) * Q * VIR$$

Where:

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

Table 1 Average European market mixes for different materials

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**	**	**	–

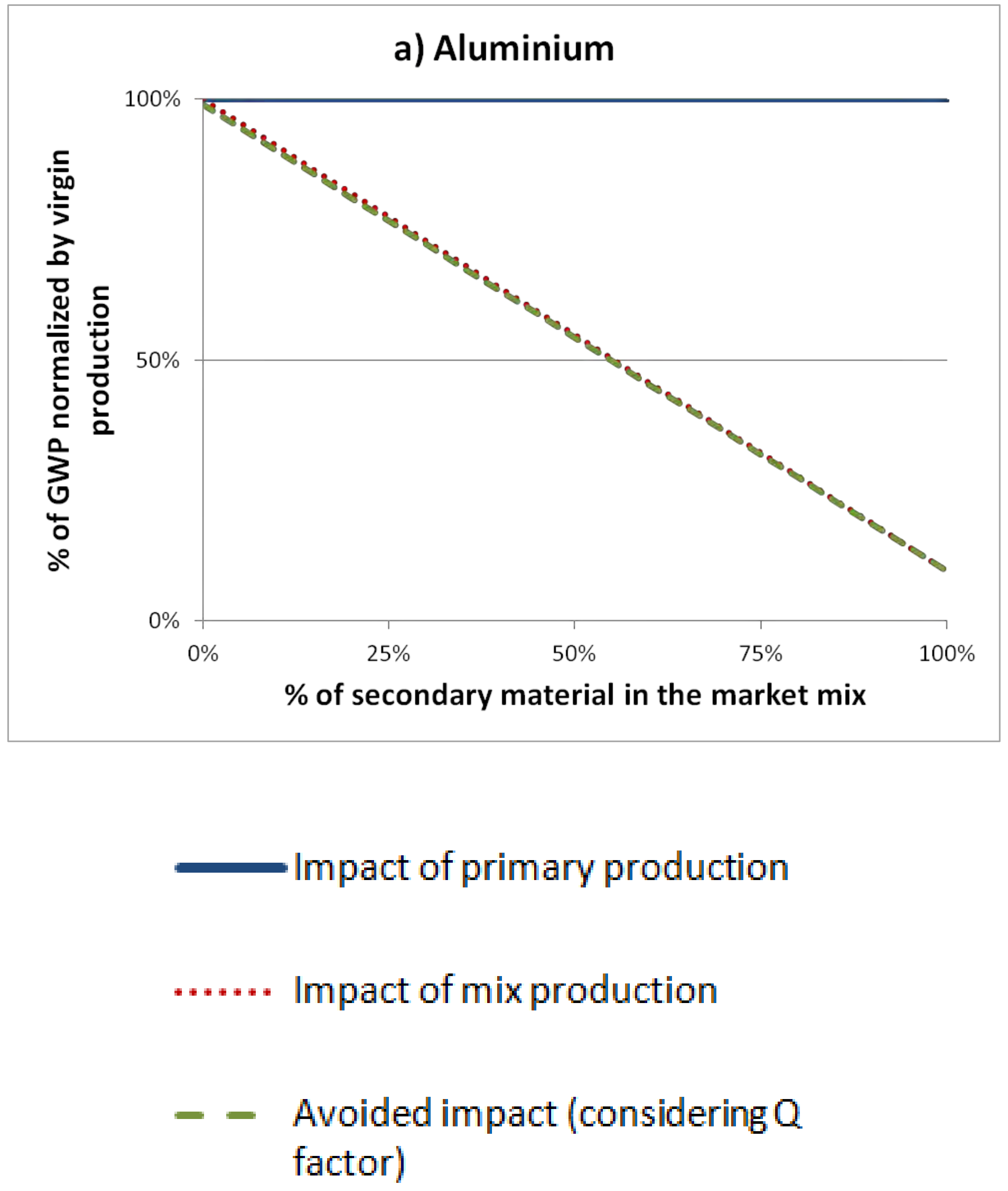
*For the packaging sector, these percentages move to 25 % of virgin and 75 % of recycled

**The percentage of recycled plastic is difficult to quantify

UNESCO CHAIR IN **LIFE CYCLE AND CLIMATE CHANGE**
ESCI School of International Studies

New approach for credits calculation

Putting the formula into practice:



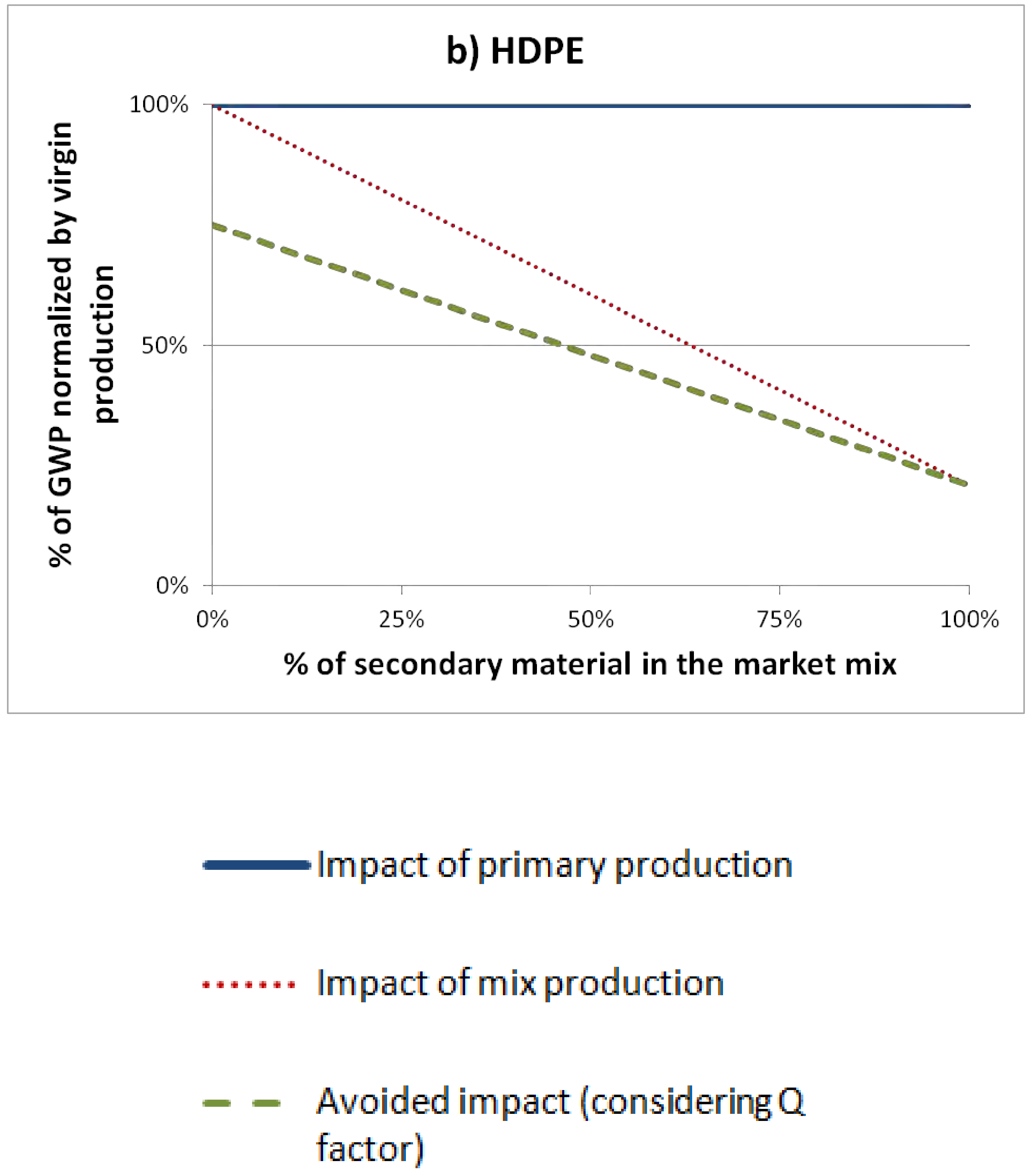
- Situation (a) (illustrated by the case of aluminium), in which the calculation of the credit mainly depends on the market mix. In this case, the impact of virgin production (VIR) is about 10 times higher than that of the recycling process (REC/VIR≈0.1). At the same time, the quality factor is virtually 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.

$$\text{Environmental credit} = x * REC + (1 - x) * \cancel{Q} * VIR$$

UNESCO CHAIR IN LIFE CYCLE AND CLIMATE CHANGE
UNESCO CHAIR IN LIFE CYCLE AND CLIMATE CHANGE

New approach for credits calculation

Putting the formula into practice:

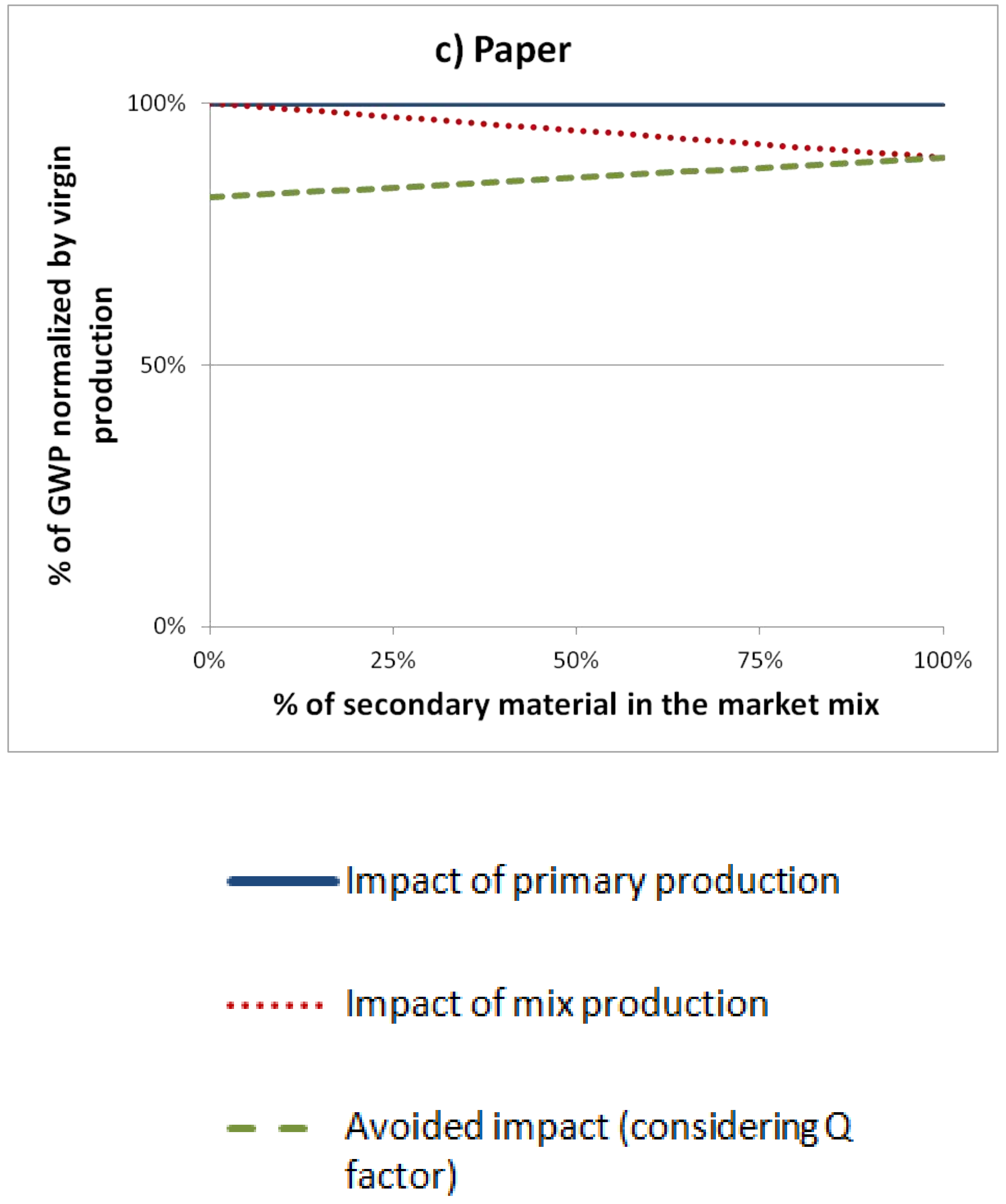


- Situation (b) (illustrated by the case of high-density polyethylene). In this case, the impact of the recycling process is still lower than that of virgin production, but the difference is not so large (REC/VIR≈0.2). Additionally, the credit is strongly influenced by the application of the quality factor (*Q*≈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.

$$\text{Environmental credit} = x * REC + (1 - x) * Q * VIR$$

New approach for credits calculation

Putting the formula into practice:



- 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 ($Q \approx 0.83$ 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 well-established mix of already mainly secondary paper products (e.g. in the packaging sector[1]) 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).

New predictive model for collection

sustainability (Currently under review) MDPI

Article

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 to the collection and transport stage.

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[(b)]	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]

New predictive model for collection

In those software, there are three levels of complexity:

- **Level 1:** Require that the user input the total amount of fuel consumed directly, and then apply fixed emission factors.
- **Level 2:** Require the input of fuel consumption (or efficiency rates) (ex. L/ton or L/km) and the input of waste 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 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 consumption factors.

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

New predictive model for collection

- We developed a new model and compared 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)

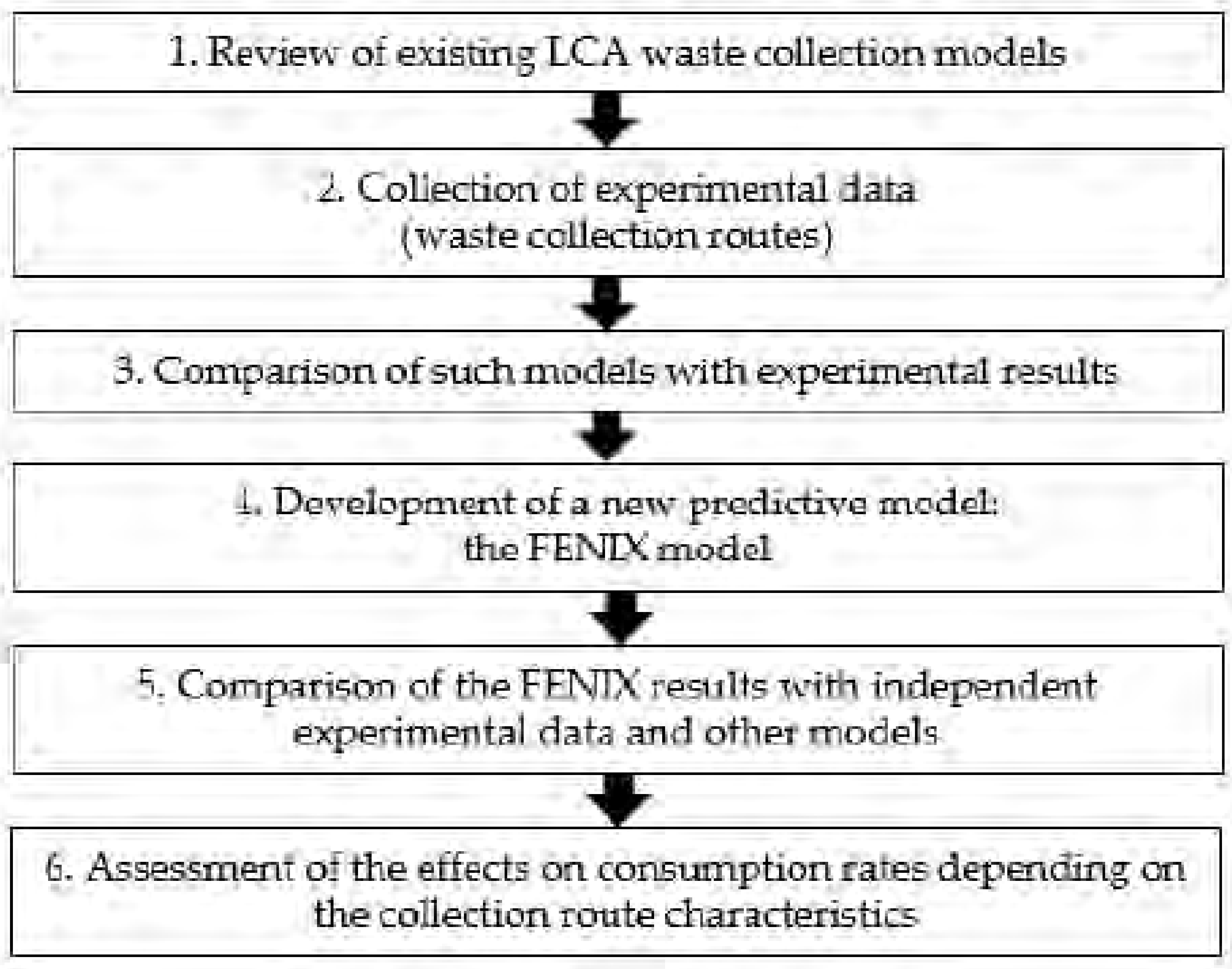
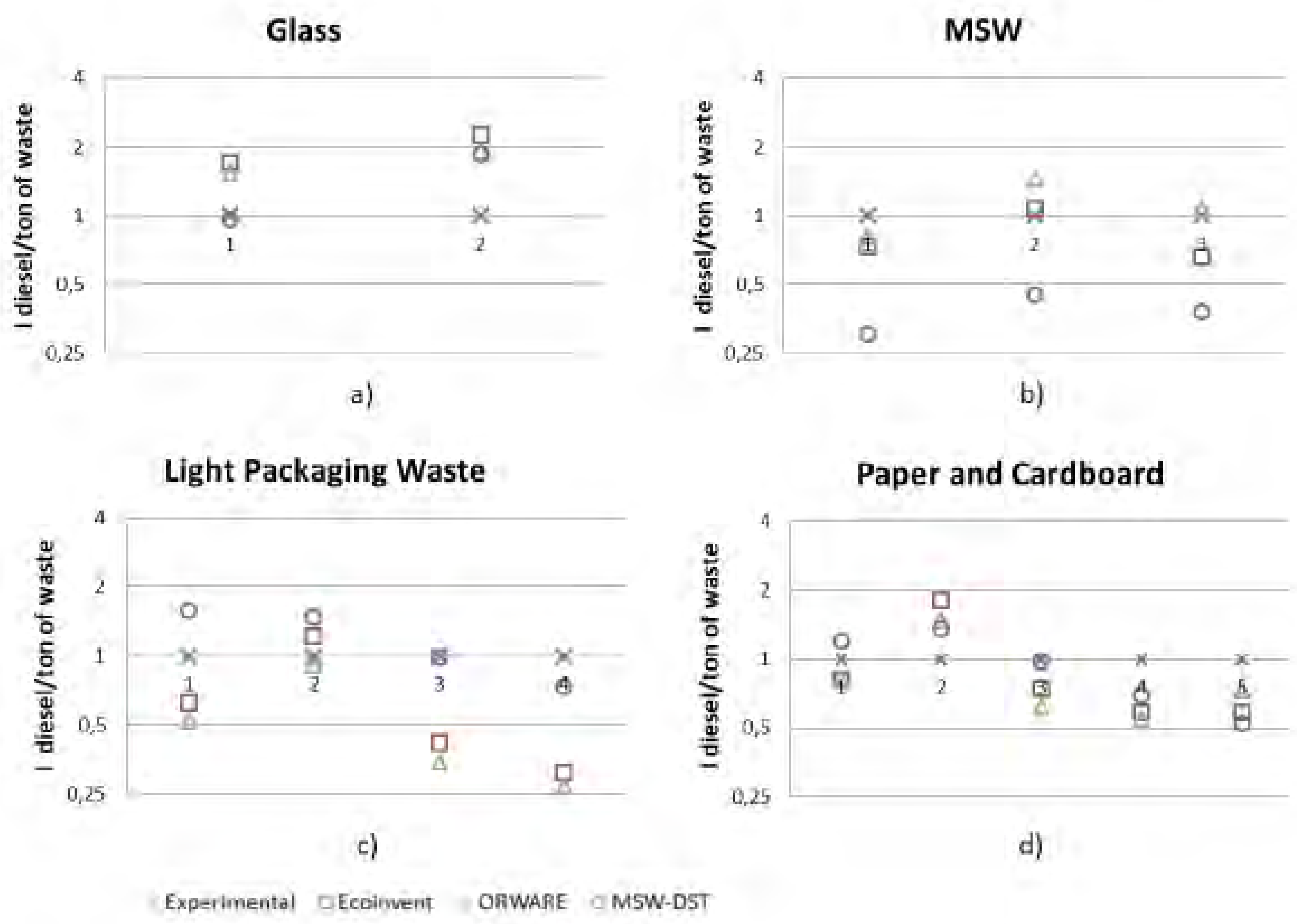


Figure 1. Research steps.

UNESCO CHAIR IN LIFE CYCLE AND CLIMATE CHANGE
UNESCO CHAIR IN LIFE CYCLE AND CLIMATE CHANGE

New predictive model for collection

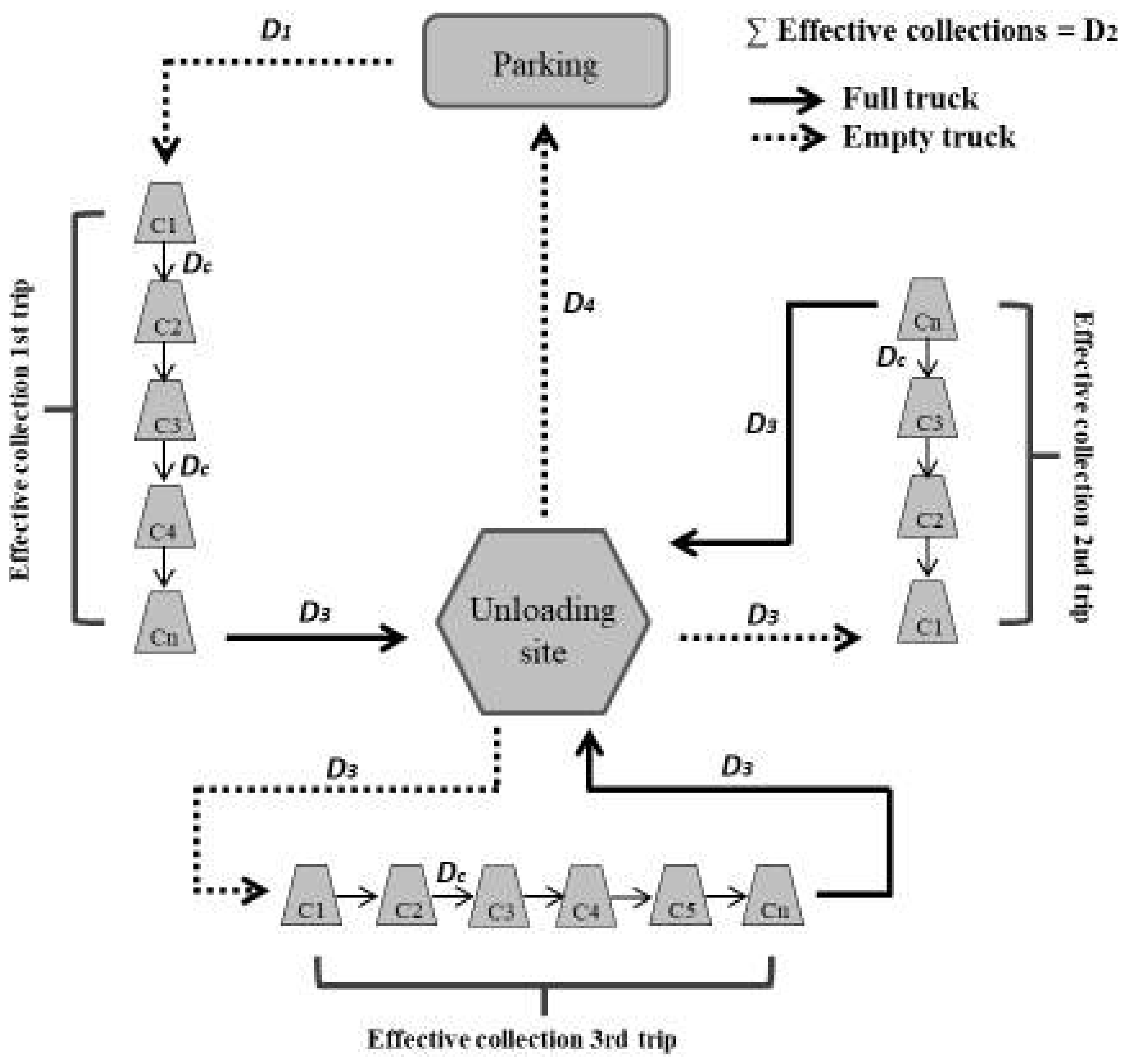


Results:

- Graphs are expressed in a base-2 log scale.
- None of the models match experimental data; only in 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 collection stage by a factor of 4!

UNESCO CHAIR IN LIFE CYCLE AND CLIMATE CHANGE

New predictive model for collection



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

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

Input Data

W_T: total amount of waste collected [kg]

dens: waste density [kg/m^3]

Freq: collection frequency [year-1]

C: number of containers [-]

V_c: average volume per container [m^3/C]

V_t: volume capacity of the truck [m^3/truck]

D_1: Distance between the parking lot and the collection route [(a)] [km]

D_3: Distance from the collection area [(a)] to the unloading site [km]

D_c: Distance in between individual containers [km/C]

D_4: Distance between the unloading site and the parking lot [km]

T_T: Duration of the working day [h]

Output Data

α_j : share of km travelled in each type of road [-]

U_r : utilization (fill) ratio of the truck by mass [-]

D_T :distance of one full trip of the waste collection truck [km]

Default parameters and intermediate calculations

βj : consumption truck correction factor [-]

Pl: maximum payload capacity of the truck [kg$_{load}$]

A_j: diesel consumption of the empty truck, depending on the type of road [kg$_{diesel}$/km]

B_j: diesel consumption of the full truck, depending on the type of road [kg$_{diesel}$l/km]

F_{comp}:diesel consumption factor while the truck is lifting containers and compacting waste [kg$_{diesel}$/h]

W_{box}: weight of the box truck [kg]

$Fill_c$: average container fill ratio [%]

cr_t: compaction ratio of the truck [-]

ef: collection efficiency in number of containers collected per hour [C/ h]

S_{col}: average speed while collecting [km/h]

S_{transp}: average speed while transporting [km/h]

T_{comp}: time spent loading and compacting waste [h]

T_{unload}: time spent unloading waste [h]

T_{luch}: time for lunch brake [h]

T_{transp}: total time spent while transporting [h]

T_{col}: time spent collecting [h]

D_2: Total distance spent while collecting waste (effective collection distance) [km]

N: number of trips per truck [-]

ESCI upf School of International Studies

New predictive model for collection

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

Waste fraction collected	Route Code	Experimental (L/t)	Relative deviation from experimental data			
			FENIX	ORWARE	MSW-DST	Ecoinvent
Glass	G1	9.1	**-0.34**	0.54	-0.04	0.70
	G2	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
	P2	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

It performs better

UNESCO CHAIR IN **LIFE CYCLE AND CLIMATE CHANGE**
ESCI upf School of International Studies

UNESCO CHAIR IN **LIFE CYCLE AND CLIMATE CHANGE**

UNESCO CHAIR IN **LIFE CYCLE AND CLIMATE CHANGE**

New predictive model for collection

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

INPUT DATA											CALCULATED DATA					
	Waste [t]	Working day[h]	Yearly Freq.	N. cont	container volume [m^3]	truck volume [m^3]	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	l/year	l/t
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
8	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.

New predictive model for collection

CONCLUSIONS

- Fixed consumption rates included in some LCA tools or database for WMS to calculate the impact of the 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 parameters of the collection route as much as possible, or conversely, use predictive models as the one presented in the paper.
- The duration of the working time has been identified as an important issue to take into account (usually neglected in LCA models or studies).

UNESCO CHAIR IN **LIFE CYCLE AND CLIMATE CHANGE**

UNESCO CHAIR IN **LIFE CYCLE AND CLIMATE CHANGE**

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.

100%

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.

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

Greater cost for society

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

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

UNESCO CHAIR IN **LIFE CYCLE AND CLIMATE CHANGE**
ESCI upf School of International Studies

UNESCO CHAIR IN **LIFE CYCLE AND CLIMATE CHANGE**

UNESCO CHAIR IN **LIFE CYCLE AND CLIMATE CHANGE**

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

ELSEVIER
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?

R. Abejón [b], J. Laso [b], M. Margallo [b], R. Aldaco [b], G. Blanca-Alcubilla [a], A. Bala [a], P. Fullana-i-Palmer [a]

ELSEVIER
Science of The Total Environment
Volume 702, 1 February 2020, 134603

Environmental assessment of the food packaging waste management system in Spain: Understanding the present to improve the future

A. Bala [a], J. Laso [b], R. Abejón [b], M. Margallo [b], P. Fullana-i-Palmer [a], R. Aldaco [b]

https://www.esci.upf.edu/es/catedra-unesco-de-ciclo-de-vida-y-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).
- Only through reverse and compacting vending machines (RVM).
- Including public RVM.
- Reverse logistic in all cases.

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.

Many thanks!

Alba Bala
Alba.bala@esci.upf.edu