An evaluation of upstream assumptions in food-waste life cycle assessments

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ABSTRACT

The aim of this paper was to evaluate the tenability of the "zero burden assumption" for a waste stream with an economic value. Thirty comparative life cycle assessments (LCAs) addressing food-waste treatment were analysed and five questions were asked: (i) was the "zero burden assumption" used and what percentage of the waste system environmental impact was contributed by food-waste production? (ii) was there any indication that the waste had economic value? (iii) was it a comparative study? (iv) was the approach different between peer reviewed journals and commercial studies? and (v) if an environmental burden were assigned to the waste in each study, how might it be estimated? It was evident that the upstream 'zero burden assumption' is commonly followed in food waste LCA and no quantitative environmental impact is associated with the food waste resource, be it a comparative study or not. Few studies acknowledged that waste has an economic value. The argument for including the environmental impact of food waste and waste in general was reasoned on two fronts. Firstly, it was shown that the environmental impact of the waste itself may hold a large percentage of the overall system impact and should therefore be included. Secondly, with the valorisation of waste and its subsequent use as a feedstock in other systems that produce a product with an economic value, it is no longer directed to a biosphere sink, and should therefore not be called a waste as it stays in the technosphere as a resource. Future food-waste and waste LCA in general could follow the approach that was explored and quantify the environmental impact of waste by using a 'meta-waste-based accounting' approach.

Keywords: Life cycle assessment, zero burden, economic value, up-stream assumptions, technosphere, meta-waste-based accounting

1. Introduction

By definition, life cycle assessment (LCA) estimates the environmental impact of a product over its entire life from conception to disposal. The application of LCA for waste system analysis has been applied at macro, meso and micro levels in a large number of countries globally (Anderson et al. 2012; Khoo et al. 2010; Saer et al. 2013). A fundamental approach in LCA methodology is the modeling of a system being carried out in such a way that inputs and outputs to the system are followed from the 'cradle' to the 'grave'. This means that input flows should be drawn from the biosphere without human transformation, and outputs should be flows that are discarded to the biosphere without subsequent human transformations (ISO, 2006a). In the case of waste LCA a common approach applied in practice since the late 1990's is known as the "zero burden assumption" (Ekvall et al. 2007). It is applied when the waste coming into two comparative systems is regarded as the same across both systems and thus can be omitted from calculations (or assumed to have zero burden). In a scenario where there are differences in the amount of wastes coming into the systems under comparison the upstream boundary may have to be changed to include the impact of producing the waste (Finnveden, 1999). This is recognised as being difficult to do in practice, as waste is a non-homogeneous product (Ekvall et al. 2007). The aim of this paper was to evaluate the tenability of the "zero burden assumption" if the waste stream has an economic value, for example as a feedstock for nutrient recovery technology. Findings are discussed in relation to identified limitations, new developments and possible future research in the waste sector.

2. Methods

This study is limited to assessing upstream assumptions in food waste (FW) LCA. Other studies have reviewed the four stage procedure for carrying out FW LCA (Bernstad and la Cour Jansen, 2012). To evaluate the upstream assumption thirty LCA studies were considered (Table 1) from four continents, Asia (5 studies), North America (3 studies), Australasia (1 study) and Europe (21 studies). Criteria for accepting a study were established based on the following:

1. Include at least one nutrient recovery technology capable of accepting FW.
2. Adhere to LCA methodology.
3. Include global warming potential (GWP) as an impact category.
4. Have been published between the years 2000 and 2014.

A review matrix was then developed for the systematic review of the thirty papers, and the following five questions were then answered:
(ia) Was the "zero burden assumption" used and (ib) what percentage of the waste system's environmental impact was contributed by food-waste production?
(ii) Was there any indication that the waste had economic value?
(iii) Was the study a comparison of more than one technology?
(iv) Was the zero waste assumption approached differently between peer reviewed journals and commercial studies?
(v) If an environmental burden were to be assigned to the waste in each study, how might it be estimated?

2.1. Reviewed studies

Table 1: Studies included in this review paper

Nr	Country	Technology	Waste type	Reference
1	Denmark	C	FW	Anderson et al. (2012)
2	Indonesia	AD/C/L	FW	Aye and Widjaya (2005)
3	Denmark	AD/C/I	FW	Baky and Eriksson (2003)
4	Turkey	C/I/L	MSW (FW)	Banar et al. (2009)
5	Belgium	AD/I/L	MSW (FW)	Belboom et al. (2013)
6	Sweden	AD/C/I	FW	Bernstad and La Cour Jansen (2011)
7	Italy	C/L	MSW (FW+GW)	Blengini (2008a)
8	Italy	AD/C/L	MSW (FW+GW)	Blengini (2008b)
9	Spain	L/C	MSW (FW)	Bovea and Powell (2006)
10	Sweden	AD/C/L	FW	Börjesson and Berglund (2007)
11	US	L/C	FW	Cabaraban et al.(2008)
12	Thailand	AD/I	MSW (FW+GW)	Chaya and Gheewala (2007)
13	Italy	AD/I/L	MSW (FW)	Cherubini et al. (2009)
14	US	AD	FW	DiStefano and Belenky (2009)
15	UK	AD/I/L	FW	Evangelisti et al. (2014)
16	Denmark	AD/I	FW	Fruergaard and Astrup (2011)
17	Italy	AD/I	FW	Grosso el al. (2012)
18	Spain	AD/I/C/L	FW	Güereca et al. (2006)
19	Singapore	AD/I/C	FW	Khoo et al. (2010)
20	South Korea	I/C/FP	FW	Kim and Kim (2010)
21	Denmark	AD/I	MSW (FW)	Kirkeby et al. (2006)
22	South Korea	I/L/C/FP	FW	Lee et al. (2007)
23	Australia	C/L	FW	Lundie and Peters (2005)
24	Spain	C	FW	Martínez-Blanco et al. (2009)
25	Spain	C	FW	Martínez-Blanco et al. (2010)
26	Italy	C/I	MSW (FW+GW)	Rigamonti et al. (2009)
27	US	C	FW	Saer et al. (2013)
28	UK	AD/C/L/I	MSW (FW)	Sonesson et al. (2000)
29	Italy	C	MSW (FW)	Tarantini et al (2009)
30	Ireland	C/L	MSW (FW)	White (2012)

C: Composting; AD: Anaerobic digestion; L: Landfill; I: Incineration; FP: Feed production; FW: Food waste; GW: Garden waste; MSW: Municipal solid waste.

3. Results

The results for question one, two and three are presented in Table 2.

Table 2: Results for question one to three.

Nr	1a	1b	2	3
1	No mention, study began with waste generated.	0%	Avoided fertiliser production.	Yes
2	No mention, study began with waste generated.	0%	Avoided electricity and fertiliser were considered. CBA carried out, comments that the end product would have an economic value.	Yes
3	No mention, study began with waste generated.	0%	Avoided electricity, heat and fertiliser were considered	Yes
4	No mention, study began with waste generated.	0%	Avoided fertiliser production was considered	Yes
5	No mention, study began with waste generated.	0%	States that an economic study using the concepts of life cycle cost would be conducted. Includes the generation of biogas.	Yes
6	No mention, study began with waste generated.	0%	Avoided electricity, heat and fertiliser were considered	Yes
7	Discusses 'zero burden' approach. Study began with waste generation	0%	Avoided fertiliser	Yes
8	Discusses 'zero burden' approach. Study began with waste generation	0%	Avoided fertiliser	Yes
9	No mention, study began with waste generated.	0%	Avoided fertiliser	Yes
10	No mention, study began with waste generated.	0%	Avoided electricity and fertiliser were considered	Yes
11	No mention, study began with waste generated.	0%	No avoided burdens were considered	Yes
12	No mention, study began with waste generated.	0%	Avoided electricity and fertiliser	Yes
13	No mention, study began with waste generated.	0%	Avoided electricity	Yes
14	No mention, study began with waste generated.	0%	Avoided electricity	No
15	No mention, study began with waste generated.	0%	Avoided fertiliser and electricity generation	Yes
16	No mention, study began with waste generated.	0%	Avoided fertiliser and electricity generation	Yes
17	Discusses 'zero burden' approach. Study began with waste generation	0%	Avoided electricity, heat and fertiliser were considered	Yes
18	No mention, study began with waste generated.	0%	No avoided burdens were considered	Yes
19	No mention, study began with waste generated.	0%	Avoided fertiliser and electricity generation	Yes
20	No mention, study began with waste generated.	0%	Avoided fertiliser and electricity generation	Yes
21	No mention, study began with waste generated.	0%	Avoided electricity	Yes
22	No mention, study began with waste generated.	0%	Avoided electricity, fertiliser and soybean	Yes
23	No mention, study began with waste generated.	0%	No avoided burdens were considered	Yes
24	No mention, study began with waste generated.	0%	No avoided burdens were considered	Yes
25	No mention, study began with waste generated.	0%	Avoided waste going to landfill	No
26	No mention, study began with waste generated.	0%	Avoided fertiliser production	Yes
27	Upstream processes discussed and excluded.	0%	Avoided peat production and NPK production	No
28	No mention, study began with waste generated.	0%	Avoided fertiliser production	Yes
29	No mention, study began with waste generated.	0%	No avoided burdens were considered	No
30	Discusses 'zero burden' approach. Study began with waste generation	0%	Avoided fertiliser production	Yes

CBA: Cost Benefit Analysis.

A limited number of commercial LCAs have been carried out for FW. From this limited analysis (question 4) it was seen that there was no difference in the approach taken for commercial FW LCA in comparison to that of the academic papers. The zero burden approach was followed for both types of analysis with four (13%) studies making reference to following the 'zero burden' approach, whilst the other twenty-six followed the approach but made no reference to it. Subsequently, none of the thirty studies (commercial or academic) associated a quantitative environmental burden to FW.

The FW entering each system in the thirty studies was different in each case, which means assessing its environmental impact in a cradle to grave system is impossible (question 5). One method for calculating the environmental impact of FW would be to follow the approach taken by Milà i Canals et al (2011) who assessed the footprint for the Knorr food portfolio. A bottom up approach was impractical in this case due the complexity of the product range, which is a similar challenge for FW LCA. The 'meta-product-based accounting' LCA approach that created sixteen product types, for example, "dry soup–instant" with an average recipe that does not exist in the market, but is a good-enough representation of the hundreds of variants of instant dry soups in the market could also be applicable to FW LCA where waste can be categorised into a number of sub-groups (vegetable, meat, grain, processed food and so on) and an environmental impact could be assigned. To illustrate this approach and the potential impact that FW could have in its simplest form, three food products (beef, tomatoes and pasta) were identified where verified LCAs have been carried out and only the impact GWP was considered (Table 3).

Table 3: GWP of three food types

Product	**kg $C0_2$ eq/kg**	**kg $C0_2$ eq/kg (Average)**	**% of waste**	**kg $C0_2$ eq/kg for % waste**	**Reference**
Beef	11-25.3	18.15	10	1.815	Casey and Holden (2005); William et al (2006)
Tomatoes	0.5-1.7	1.1	80	0.88	Hogberg (2010)
Pasta	0.85-2.5	1.675	10	0.1675	Barilla (2013)

If it was assumed that FW consisted of 80% tomatoes, 10% pasta and 10% beef a GWP of approximately 2.9 Kg CO_2-e per Kg of FW would be estimated (Table 3). This is a similar value to the estimated two tons of CO_2 per tonne of FW (European Commission, 2010).

Table 4: Adapted from Blengini, (2008a), GWP impact for FW composting system

Process	**Kg CO_2 eq/kg**	**Percentage**
Waste bags†	0.017	0.53
Road transport†	0.012	0.38
Waste processing†	0.045	1.41
Biogenic Emissions from composting†	0.156	4.88
Avoided Products and carbon sinks†	-0.10	3.13
Waste generation	2.8655	89.67
Total	3.1955	100

†Number are approximations taken from graphs in the original publication.

Taking Blengini's (2008a) research as a case study (FU is 1 kg of waste and has detailed breakdown of process GWP impacts) and including the embedded GWP impact of waste (Table 4) it can be seen that waste generation has a considerable impact at approximately eighty-nine per cent of the total.

4. Discussion

In relation to FW LCAs and according to the ISO standard (ISO, 2006) an LCA should be carried out in such a way that inputs and outputs to the system are followed from the 'cradle' to the 'grave'. It has been identified in this paper that this is not the case for LCA carried out for FW and waste in general. The 'zero burden' assumption has been followed for well over a decade in waste studies, comparative or not, and was seen in all thirty of the studies reviewed, with the result being that waste was not given a quantitative burden in waste systems when carrying out life cycle analysis.

All of the thirty studies included a nutrient recovery technology that produced a product that has an economic value that could offset some or all of the inherent negative economic value of the waste, however the majority of the studies made limited reference to waste having an 'economic value' as a resource, although twenty-five studies had an avoided burden associated to the replacement of a fossil material. The fact that this resource stream stays in the technosphere and does not enter the biosphere as a waste as per the definition of 'grave' by the ISO standard (ISO, 2006) means that it should be referred to as a resource (Figure 1).

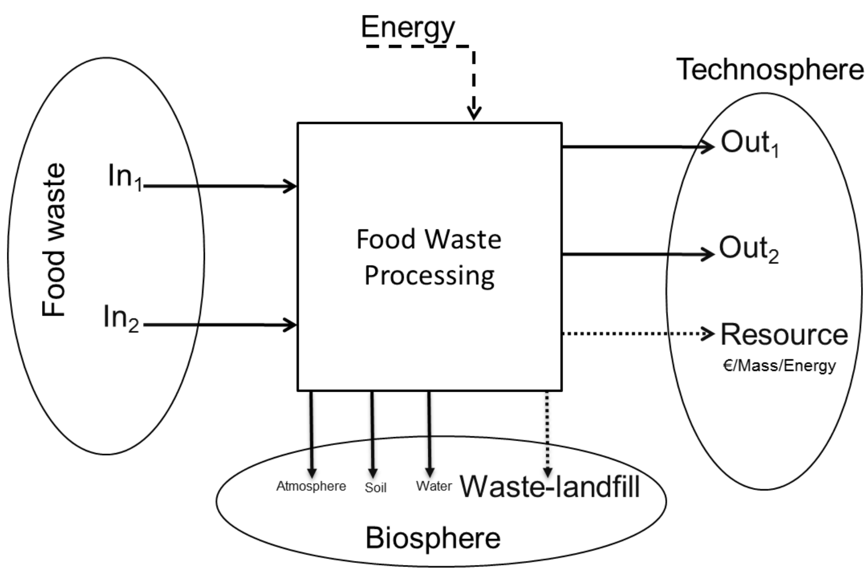

Figure 1: Waste verses resource

The term 'circular economy' is increasingly being used by governments and organisations (Mirabella, 2014) that are trying to find ways to close the loop on waste. This means it is used as a resource in other systems, such as a feedstock or raw-material replacement. In the case of biological nutrients found in FW this could be by composting or another nutrient recycling technology. However, the waste hierarchy defines that waste minimisation be the priority and in the case where reductions cannot happen it proposes that, reuse, recycling and recovery be achieved in that order. These two approaches can be seen as contradictory. In the case of adopting nutrient recovery technologies that would require investment and are privatised in many European countries, a return on investment and subsequent profit would be expected, which would come from the products produced (in addition to gate fee). Therefore it can be assumed that the owner of the facility would have no incentive to reduce the waste collected as this would decrease profit. This may not be the case in all locations across Europe, but with sustainability at the forefront of government policy and recycling rates on the increase waste can no longer be seen as a valueless resource, and must be dealt with in a manner that not only considers its economic value, but also the associated environmental burden.

This valorisation of waste, which has resulted in it becoming a feedstock for a number of technologies means that there is a strong relationship between its economic value and the amount that is available. In a case where 20% of total food produced is wasted (Figure 2) and becomes a feedstock in a recovery technology there will be a much stronger relationship between its economic value and the amount of the waste (20%) than that of the economic value and mass of the consumed food (80%). It can be argued that in this example where 80% of food produced is consumed that the economic value of this food or its disposal would have to increase significantly if this were to be the over-riding relationship between the amount of food wastage and amount food consumed.

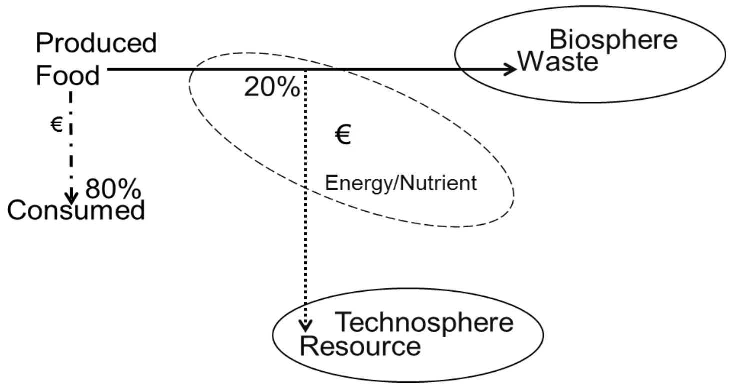

Figure 2: Relationship between the amount of waste and its value

5. Conclusion

In carrying out this review it was found that in response to the five questions asked: (1) the "zero burden assumption" was followed in all the studies thus no impact was assigned to food waste generation in all cases; (2) in five of the studies there was no reference to economic value, one study carried out a cost benefit analysis, whilst in the remaining twenty-four the product of the conversion process, i.e. compost or energy was identified as having a substitute value, but no value was mentioned for the food-waste itself ; (3) twenty-six of the studies compared two or more technologies; (4) the approach followed is the same for both academic journal and commercial studies; (5) the food waste entering each system in the thirty studies was different in each case, which means assessing its environmental impact in a cradle to grave system is very difficult.

It is evident that the upstream "zero burden assumption" is commonly followed in food waste LCA and no quantitative environmental impact is given to the food waste resource. The argument for including the environmental impact of FW and waste in general was presented on two fronts, firstly, it was shown that the environmental impact of the waste itself may hold a large percentage of the overall system impact and should therefore be included to show likely decreases if waste reduction occurs. Secondly, with the valorisation of waste and its subsequent use as a feedstock in other systems that produce a product with an economic value, it is no longer directed to a biosphere sink, and should therefore not be called a waste as it stays in the technosphere as a resource. Future FW and waste LCA in general could follow the approach that is suggested above and quantify its environmental impact by using a'meta-waste-based accounting' approach.

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