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Extended Waste Management Pinch Analysis (E-WAMPA) Minimising Emission of Waste Management: EU 28

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Waste recovery and disposal are one of the biggest management challenges. An adequate waste management design is critical in contributing to the development of a sustainable circular economy. There is a need for a systematic and preferably graphical approach to assessing the emissions associated with waste treatment processes followed by strategies for mitigation. This study aims to propose a graphical approach in identifying the appropriate waste management system (WMS) with lower emissions. The proposed graph-based approach termed as Extended-Waste Management Pinch Analysis (E-WAMPA) is an extension to the existing WAMPA. It is distinguishable by three major issues a) Emission intensity of WMS (Net GHG per capita) and stagewise algorithm aims for regional waste management planning are introduced, b) the emissions of recycling are not assumed as zero c) The demonstration is based on the defined targets, projection and power grid mix of EU. A generic methodology of E-WAMPA is presented and followed by the European Union- 28 member states (EU-28) case study to elucidate the application. The considered waste type is the municipal solid waste (MSW), and the assessed emission is GHG. E-WAMPA is capable of suggesting the strategies in fulfilling the targeted emission reduction of a region (e.g. 10 % reduction) and meeting the individual treatment targets. One of the possible strategies is demonstrated on adjusting the WMS of Malta, Greece, Cyprus and Romania. The way forward of E-WAMPA have been discussed as well.

1. Introduction

Waste treatment plays an important part in the waste management system (WMS) after the effort of waste prevention. Improper waste management contributes to environmental issues such as greenhouse gas (GHG) emission, air, ground and water pollution. A wide range of waste recovery approaches includes material recycling, waste to energy and biological recovery have been introduced to support continuing economic growth and industrial development, by minimising the impact of waste generation. Recovery process consumes energy and releases GHG in the process of mitigating the footprints of waste. Various approaches have been applied to identify suitable waste treatment options and management systems. These include heuristic methods, multi-criteria decision analysis, graphs and network theory, mathematical optimisation, stochastic process techniques and statistical methods (de Souza Melaré et al., 2017). Ho et al. (2017) stated that most of the proposed model is performed by a “black box” mathematical optimisation approach which is difficult to understand the reason in obtaining the optimal solutions fully. Studies proposed graphical approach is comparatively few. One such approach is the Pinch Analysis. This methodology has been widely applied to different fields and has the advantages to be easily understood. Linnhoff et al. (1982) are the main pioneers of Heat Recovery Pinch in solving the Heat Integration problem. There were various extensions of Pinch Analysis include for hydrogen integration, mass integration, water network synthesis, power system planning and regional resource planning (Klemeš et al., 2018). Tan and Foo (2007) developed an extension of Pinch Analysis as Carbon Emission Pinch Analysis (CEPA) for optimal allocation of energy sources based on the GHG emission constraints. It has been successful due to its capability to capture and communicate the challenge and opportunities in energy planning for low-GHG emissions. CEPA has been later introduced by Ho et al. (2017) to the waste management area as Waste Management Pinch Analysis (WAMPA). The modification includes (a) the non-carbon emitting option is 3R (reduce, reuse and recycling) instead of

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renewable energy as in the CEPA and (b) landfill reduction target is introduced. It was demonstrated by a hypothetical case study of five waste types. WAMPA approach has been later applied to a case study of China (Jia et al., 2018) using site-specific data. The y-axis and x-axis of WAMPA are GHG emissions and waste amount. The absolute value could mask some of the important information for an appropriate waste strategy planning, particularly if involving the net emissions accounting or comparison between countries. An improved method which considered the life cycle emissions (possibly using footprints) and a population of a country is needed. The country with high recovery rate is not necessary the countries with the lowest emission as the waste amount could be significant. The presented study introduces the intensity of WMS as the selecting approach in identifying the potential of a country for improvement (emission reduction). It represents net emission per capita (in this study specifically to GHG). The net GHG emission is accounted by the amount of emission emitted from the treatment processes and the emission mitigated from material reprocessing and avoided primary production. The study aims to propose a graphical approach in identifying the WMS (a set of waste treatments) with lower emissions. The proposed graphical approach is an extension to the existing WAMPA, which is extended initially from CEPA approach, inspired by the concept of Pinch Analysis. In this study, the approach is referred to as E-WAMPA, representing Extended-WAMPA. The applicability of E-WAMPA is demonstrated through a case study of the EU. It facilitates the waste treatment selection by suggesting the strategies (share of different waste treatments) based on defined targets (e.g. recycling rate, waste amount, landfill reduction). The novel contributions of this work include:

i. The intensity of the WMS (Net GHG emission per capita) is introduced as an indicator of the potential reduction of a country. It could better reflect the net emission of a country than the absolute value.
ii. The step by step algorithm of WAMPA is improved by considering the limitation in developing WAMPA. For example, the assumptions of 3R activities have no emission, WtE is given priority over 3R due to energy production and economic reasons, which are not truly reflecting the real-life condition.
iii. The applicability is demonstrated by EU-28 case study rather than a hypothetical case study. The demonstration is based on the defined targets and projection of the EU. E-WAMPA is capable in proposing a WMS that meeting the emission reduction targets of a country, region or globally.

2. Methodology

The methodology is divided into two major sections. Section 2.1 and 2.2 present the generic method that independent of the case study. The approach in identifying the emission intensity of waste treatment practices in a place is presented in Section 2.1. A step by step algorithm of E-WAMPA in identifying the potential mitigation strategies is introduced in Section 2.2.

2.1 Emission Intensity of Waste Management System (WMS)

The emission intensity of the WMS is determined by using Eq(1). Emission intensity including carbon emissions intensity has been commonly used as an indicator to evaluate the environmental performance of energy source in the unit of CO_2eq/GDP (Dong et al., 2018), where a lower value is representing a greener energy source (e.g. higher share in renewable energy). Eq(1) is based on a similar idea, but the emissions are divided by per population. It is determined by summing the net emission contribution of each waste treatment alternatives ($E_{\mathrm{emitted}} - E_{\mathrm{avoided}}$, t of emissions) divided by population (p, capita). This study considers GHG (CO_2, CH_4, N_2O), but further emissions can be accounted for by using this approach as well.

$$T_{\mathrm{netEwaste/cap}} = \frac{\sum_t (E_{\mathrm{emitted}} - E_{\mathrm{avoided}})}{p} \tag{1}$$

Where t is representing the waste treatment alternatives, E_{emitted} is the emission release by the waste treatment processes, E_{avoided} is the emission mitigated by primary production and material reprocessing (Fan et al., 2019). For example, the emission mitigated by the energy produced from incineration. The mitigated emission is based on the current practice of energy production, and different countries have a different magnitude of saving due to the different energy mix. The lower value of WMS emission intensity ($T_{\mathrm{netEwaste/cap}}$) represents the environmental performance better. In some cases, the value is in negative and suggests the waste treatment practices achieve emission saving (Turner et al., 2015). It may be through recycling as it can replace the primary production of virgin products. It does not represent the achievement of sequestration as the assessment boundary does not include the emission of waste production.

2.2 Pinch Analysis

This section presents the E-WAMPA framework for extended application in waste management. The definition of Pinch Point and the Demand Curve are the same as of WAMPA (Ho et al., 2017), refer to the emission reduction target. Waste treatment alternatives and countries represent the Supply Curve. E-WAMPA is presented as a 2D-graph where the x-axis is the cumulative waste amount and the y-axis is the cumulative emissions (NetGHG emission). The generic step by step algorithm of E-WAMPA:

(i) Step 1, Supply Curve 1 (the red line):

Construct the stacked curve of countries (Figure 1) using the cumulative waste amount as the x-axis and cumulative emission (NetGHG emission) as the y-axis. The countries are arranged in a sequence based on emission intensity (Net GHG emission per capita). The countries arranged at the end of the cumulative curve represent the countries where the environmental performance of the WMS has an increasingly larger room for improvement. It will be the targeted countries to be altered for meeting the reduction target.

(ii) Step 2, Supply Curve 2 (the red line):

Construct the stacked curve based on the treatment system of targeted countries as in Step 1. In this study, the Supply Curve 2 represents by the Recycling Curve, Energy Recovery Curve, Composting and Anaerobic Digestion Curve, Disposal by Incineration Curve and Landfill Curve, following the classification by the EU. The treatment alternatives are arranged by sequencing based on the increasing net emission per amount of waste processed. The net emission per amount of waste processed varies across the countries mainly as the energy mix is different, contributing to the different E_{avoided}.

(iii) Step 3, Optional (the yellow line):

In this specific case study (see Section 3), an additional line/curve is constructed. It represents the waste treatment situation of the EU country in the year of 2017. It is mainly to show the changes in the waste amount in 2030. This provides a picture closer to the real-life situation as the waste amount change (either increase or decrease) along at the defined future target of emission reduction and WMS.

(iv) Step 4, Target:

The emission reduction target of a region is defined. E.g. In the case study, the reduction target of EU-28 is to minimise overall emission by 10 %. That is the target (Pinch Point) to be achieved.

(v) Step 5, Pinch Analysis - The Shifting (labelled as the green line):

Shift the Supply Curve 2 based on the define targets of waste treatment options. Adjust the amount of waste to the other recovery or disposal options until the target at Supply Curve 1 is satisfied.

3. Case study

The proposed methodology is demonstrated using the EU-28 scenario. The considered countries include Austria (AT), Belgium (BE), Bulgaria (BG), Croatia (HR), Cyprus (CY), the Czech Republic (CZ), Denmark (DK), Estonia (EE), Finland (FI), France (FR), Germany (DE), Greece (EL), Hungary (HU), Italy (IT), Latvia (LV), Lithuania (LT), Luxembourg (LU), Malta (MT), Netherlands (NL), Poland (PL), Portugal (PT), Romania (RO), Slovakia (SK), Slovenia (SL), Spain (ES), Sweden (SE) and the United Kingdom (UK). Ireland has not been included as the data were not found. Table 1 shows the input data required to estimate the E_{avoided} and E_{emitted}, see Eq(1). Table 2 shows the data inputs of the EU. The carbon emissions intensity is used to identify the emission saving from energy recovery processes. The increase in the waste amount in the year 2030 is assumed to be handled based on the same practices (% of share) as in 2017. The common EU target has been 65 % recycling of MSW by 2030 and reduces landfill to a maximum of 10 % (EC, 2017). The situation in EU countries is varying where some of the countries have already achieved the 10 % landfill target. The priorities of shifting are targeted for the countries with high net GHG emission per capita as described in Section 2.2, Step 1. The target/pinch point of this case study is to reduce the net GHG emission of EU WMS by 10 % and the waste to the landfill has to be reduced by 50 %.

Table 1: The emission/output of waste treatment and disposal processes

Treatment	GHG emitted	Output	Comment
Landfill	568 kg CO_2eq/t^{e}	-	-
Incineration	386 kg CO_2eq/t^{c}	315 kWh/t^{a}, 795 kWh/t^{b}	For disposal, energy is not recovered.
Composting	26.3 kg CO_2eq/t^{d}	600 kg/t of compost[j]	Compost contains 0.03 % of nitrogen. 3.6 t CO_2eq/t N^{h}
Anaerobic digestion	228.5 kg CO_2eq/t^{f}	150 m^3/t of biogas, 1.81 kWh/ $m^{3\ a}$, 2.27 kWh/ $m^{3\ b}$, 0.9t/t of digestate[i]	Digestate contains 0.01 % of nitrogen. 3.6 t CO_2eq/t N^{h}
Recycling	Net GHG= - 845.35 kg CO_2eq/t^{g}		MSW consists of 55 % paper, 21 % plastic, 9 % glass, 15 % metal

[a]electricity, [b]heat, [a,b,c,d](Thinkstep AG, 2017), [e](Ritchie and Smith, 2009), [f](Phong, 2012), [g](Turner et al., 2015), [h,i](Fan et al., 2018a), [j](Fan et al., 2018b)

Table 2: Data inputs of EU case study

	Waste amount (kt)		Population (M cap)		CO_2 intensity[c]	Share (%), 2017[d]				
Country	2017[a]	2030[b]	2017[a]	2030[b]	(gCO_2/kWh)	Landfill	D10	R1	R	C&A
AT	5,018	5,352	8.803	8.946	85.1	2	0	39	26	32
BE	4,659	5,350	11.391	12.002	169.6	1	1	43	35	20
BG	3,080	3,306	7.080	6.431	470.2	62	0	3	27	8
HR	1,716	1,703	4.125	3.896	210.0	75	0	0	22	2
CY	547	624	0.858	1.282	676.9	82	0	0	15	2
CZ	3,643	3,848	10.590	10.528	512.7	48	0	17	27	7
DK	4,503	4,983	5.765	6.025	166.1	1	0	53	27	19
EE	514	523	1.317	1.254	818.9	21	0	47	28	4
FI	2,812	3,080	5.513	5.739	112.8	1	0	59	27	13
FR	34,393	36,021	67.042	67.894	58.5	22	0	35	24	19
DE	52,342	54,400	82.688	82.187	440.8	1	4	27	49	18
EL	5,415	5,966	10.744	10.784	623.0	80	0	1	15	4
HU	3,768	3,886	9.787	9.235	260.4	49	0	16	27	8
IT	29,583	29,855	60.496	58.110	256.2	26	1	20	31	22
LV	851	882	1.942	1.747	104.9	51	0	5	31	13
LT	1,286	1,382	2.826	2.718	18.0	33	0	18	24	24
LU	362	434	0.596	0.675	219.3	2	0	15	10	73
MT	283	304	0.468	0.440	648.0	93	0	0	7	0
NL	8,787	9,816	17.128	17.594	505.2	1	1	43	26	28
PL	11,969	12,001	37.996	36.616	773.3	42	2	23	27	7
PT	5,012	4,890	10.291	9.877	324.7	50	0	21	12	18
RO	5,325	5,301	19.577	18.464	306.0	80	0	5	8	7
SK	2,058	2,024	5.444	5.387	132.2	61	0	10	21	9
SL	974	1,030	2.067	2.059	254.1	13	0	10	56	21
ES	21,530	21,226	46.601	46.115	265.4	54	0	13	18	15
SE	4,551	5,123	10.068	10.712	13.3	0	0	53	31	15
UK	30,911	36,720	66.049	70.579	281.1	17	1	37	28	17

[a,d](Eurostat, 2019), [b](Kaza et al., 2018), [c](EEA, 2018). D10 = incineration (disposal, without energy recovery), R1 = energy recovery, R = material recycling. C & A = composting and anaerobic digestion. The 2030 projection is based on the year of 2015 by Kaza et al. (2018). Some of the data might not be able to reflect the exact situation, but it is based on the collected data from the sources as cited. The accuracy of the data is not the main issue as it is mainly used to demonstrate the applicability of the proposed method.

4. Results and Discussion

Figure 1 shows the cumulative emission and waste amount of the assessed EU countries in 2017 (yellow line) and 2030 (red line), arranged in increasing emission intensity. The average emission intensity of the EU is -0.05 tCO_2eq/cap. Germany, Slovenia, Netherlands, Estonia, Denmark and Belgium are well above the average. Germany is one of the top ten countries with the high absolute amount of waste (Table 2), but in tCO_2eq/cap it has the best performance, contributed by the WMS which capable in mitigating the footprint of waste and lower waste generation per capita. Malta, Greece, Cyprus and Romania which located at the end of the red line are the selected countries for improvement. The demonstrated case study focuses on only one strategy- treatment transition (switch to treatment options with lower emission). The other possible strategies are waste trading (import and export activities based on treatment capacity) and enhancing treatment efficiency. Figure 2 shows the shifts (treatment transition) in Malta, Greece, Cyprus and Romania contribute to the reduction of EU emission of WMS (-25,546 to -28,114). Following the E-WAMPA methodology, one of the possible solutions is:

i. In Malta (MT): send 50 % waste for landfill to D10
ii. In Greece (EL): send 50 % waste for the landfill to D10, R1, C&A
iii. In Cyprus (CY): send 50 % waste for the landfill to C&A
iv. In Romania (RO): send 50 % waste for the landfill to R1 and D10 as shown in Figure 2

The shifting contributed to the decrease (10%) in the overall WMS emission of EU and met the Pinch point (Figure 3). The zoomed view shows the shift where waste emissions are reduced despite handling the same amount of waste (260,030 kt). Data availability on the waste treatment capacity could further improve the feasibility of the allocation and waste trading.

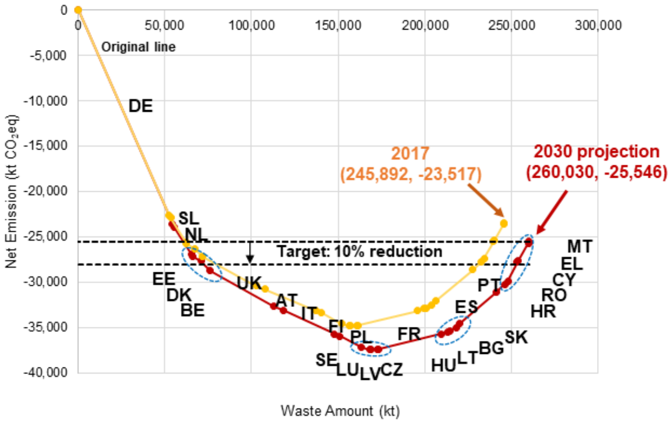

Figure 1: E-WAMPA for the waste management system of EU counties in 2017 and 2030 - Supply Curve

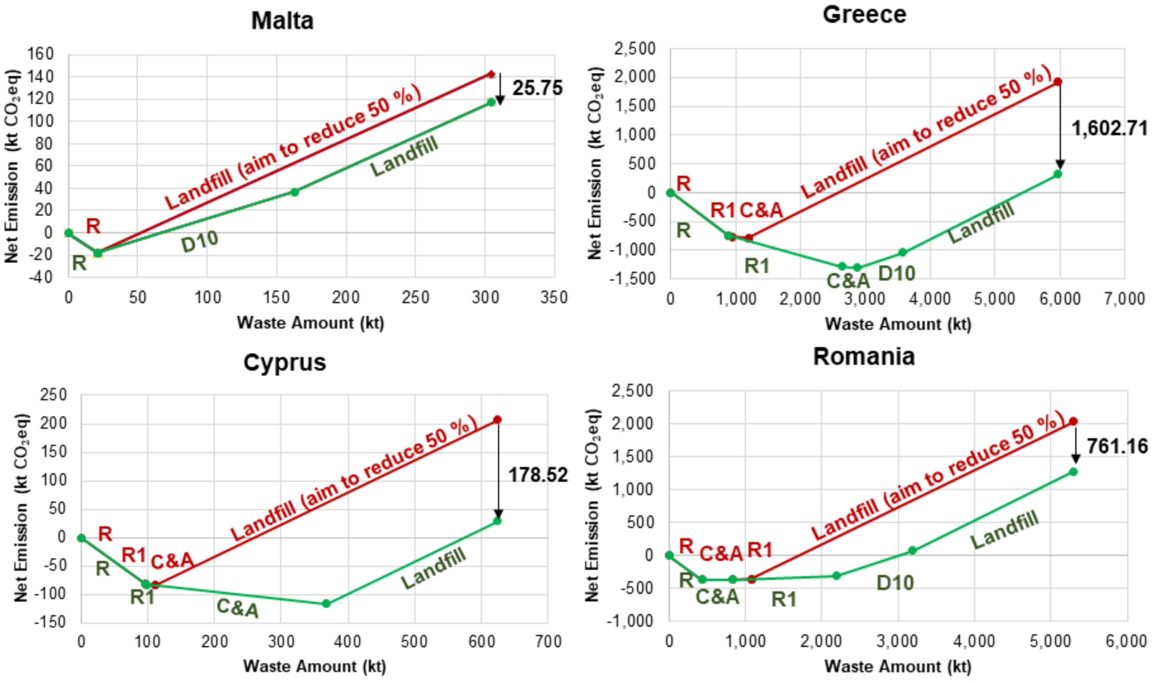

Figure 2: Treatment transition of Malta, Greece, Cyprus and Romania

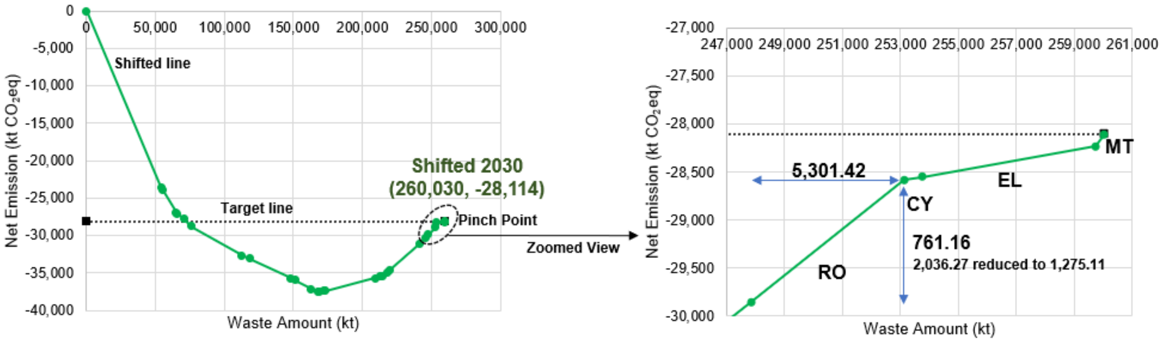

Figure 3: E-WAMPA for the waste management system of EU countries- Shifted Curve and its zoomed view

5. Conclusions

This work proposed E-WAMPA to facilitate the waste allocation in WMS towards emission mitigation graphically. The applicability of E-WAMPA is demonstrated through a possible reduction strategy (treatment transition). Malta, Greece and Cyprus and Romania are chosen as the demonstrated countries as the net GHG emission from the waste treatments per capita are high, representing the room for improvement toward emissions reduction of EU. The future research will further elaborate on the E-WAMPA methodology. The extended potential for proposing a WMS by considering the variation in waste amount and composition while meeting the treatment target and the overall emission reduction target of a region will be demonstrated. The additional future scope includes integrating the waste transportation issues (supply chain), virtual footprints, energy return on investment of waste treatment process as well as a circular economy concept to E-WAMPA.

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References

de Souza Melaré A.V., González S.M., Faceli K., Casadei V., 2017, Technologies and decision support systems to aid solid-waste management: a systematic review. Waste Management, 59, 567-584.

Dong F., Yu B., Hadachin T., Dai Y., Wang Y., Zhang S., Long R., 2018, Drivers of carbon emission intensity change in China. Resources, Conservation and Recycling, 129, 187-201.

EC (European Commission), 2017, Review of waste policy and legislation <ec.europa.eu/environment/waste/target_review.htm> accessed 28 February 2019

EEA (European Environment Agency), 2018, CO2 emission intensity. <www.eea.europa.eu/data-and-maps/daviz/co2-emission-intensity-5> accessed 28 February 2019

EuroStat, 2019. Municipal waste by waste management operations (env_wasmun) <ec.europa.eu/eurostat/web/environment/waste/database> accessed 28 February 2019

Fan Y.V., Klemeš J.J., Lee C.T., 2018a, Pre-and post-treatment assessment for the anaerobic digestion of lignocellulosic waste: P-graph, Chemical Engineering Transactions, 63, 1-6.

Fan Y.V, Lee C.T., Klemeš J.J., Chua L.S., Sarmidi M.R., Leow C.W., 2018b, Evaluation of effective microorganisms on home scale organic waste composting. Journal of Environmental Management, 216, 41-48.

Fan Y.V., Klemeš J.J., Lee C.T., Perry S., 2019, GHG Emissions of Incineration and Anaerobic Digestion: Electricity Mix, Chemical Engineering Transactions, 72, 145-150.

Ho W.S., Hashim H., Lim J.S., Le, C.T., Sam K.C., Tan S.T., 2017, Waste Management Pinch Analysis (WAMPA): Application of Pinch Analysis for greenhouse gas (GHG) emission reduction in municipal solid waste management. Applied Energy, 185, 1481-1489.

Jia X., Wang S., Li Z., Wang F., Tan R.R., Qian Y., 2018, Pinch analysis of GHG mitigation strategies for municipal solid waste management: A case study on Qingdao City. Journal of Cleaner Production, 174, 933-944.

Kaza S., Yao L., Bhada-Tata P., Van Woerden F., 2018, What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. Urban Development. Washington, DC: World Bank, USA.

Klemeš J.J., Varbanov P.S., Walmsley T.G., Jia X., 2018, New directions in the implementation of Pinch Methodology (PM). Renewable and Sustainable Energy Reviews, 98, 439-468.

Linnhoff B., Townsend D.W., Boland D., Hewitt, G.F., Thomas B.E.A., Guy A.R., Marsland R.H., 1982, last edition 1994, A user guide on process integration for the efficient use of energy. IChemE, Rugby, UK.

Phong N.T., 2012, Greenhouse gas emissions from composting and anaerobic digestion plants. PhD Thesis, University of Bonn, Bonn, Germany. <d-nb.info/104305586X/34> accessed 28 February 2019.

Ritchie N., Smith C., 2009, Comparison of greenhouse gas emissions from waste-to-energy facilities and the Vancouver landfill. Technical Memorandum, 3, 1-12. <pentz.com/NoIncinerator/greenhouse%20 Emmissions.pdf> accessed 28 February 2019

Tan R.R., Foo D.C.Y., 2007, Pinch analysis approach to carbon constrained energy sector planning. Energy, 32(8):1422–1429.

Thinkstep AG, 2017, GaBi software system and database for life cycle engineering, Stuttgart, Germany.

Turner D.A., Williams I.D., Kemp S., 2015, Greenhouse gas emission factors for recycling of source-segregated waste materials. Resources, Conservation and Recycling, 105, 186-197.