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The Potential of Carbon Emission Footprint Reduction from Biowaste in Mixed Municipal Solid Waste: EU-27

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Waste treatment and recovery is a critical management challenge. It plays an essential role in narrowing the circular economy loop by reintegrating the products into the system when they reach the end of life. This study aims to assess the waste composition of the EU-27 and identifies the potential carbon emission footprint (CF) reduction through waste treatment transition of bio-waste in mixed municipal solid waste (MMSW). The relationship between the waste composition and socio-economic factors is evaluated by regression analysis. This is to estimate the missing data (in not well-documented countries) on the share of bio-waste in MMSW. Based on the amount of biowaste disposal to the landfill, the potential of CF can be determined when proportionally decreased by the estimated share through waste recovery. The emission reduction potential is different across the countries and waste types due to the differences in the avoided emission through treatment options (e.g. the current countries' energy mix – the portion of renewable and non-renewable energy). A saving ranging from 35 - 75 % of CF reduction can be achieved in the EU. The results illuminate the significant contribution of bio-waste recovery as a mean for CF reduction and generation of renewable energy. Sensitivity analysis can be conducted in the future work, and the scope of assessment can be extended to cover a broader range of environmental footprints for a more comprehensive comparison.

1. Introduction

Waste management sector views as having great potential in greenhouse gas (GHG) mitigation (EEA, 2019), either done through waste prevention or waste recovery. The composition of waste and waste treatment/disposal determines the net GHG emission savings. Although landfilling (disposal) is generally known as the least favourable option contributing to a significant amount of GHG, the implementation of waste treatment/recovery remains a challenge. It is subjected to various barriers, including economic feasibility, social concern, government policy, as well as the current waste separation practice and infrastructure.
There have been different studies assessed the potential GHG savings from waste management to highlight the importance of shifting the waste away from landfill. Rajaeifar et al. (2017) estimated that, by recovering the municipal solid waste (MSW) for electricity generation, 0.5 % (4.8 Mt CO_{2eq}) of the annual GHG emissions in Iran could be reduced. Wang et al. (2020) suggested that the existing biomass resources in the Canadian province of British Columbia could yield 110 - 176 PJ/y of energy, reducing 13 - 15.7 % of GHG emission. Iqbal et al. (2019) performed an analysis for the case of Hong Kong, using to the landfill by baseline scenarios, and found that food waste treatment can save up to 56 % of GHG emission from landfill. A study is conducted by Ghosh et al. (2019) to identify the CH_4 saving and energy recovered by treating the MSW in the landfills of Delhi. However, studies focus on biowaste fraction in mixed municipal solid waste (MMSW) is still lacking, and the data is not well established/recorded as summarised in Table 1. Karimipour et al. (2019) highlighted the potential opportunities for further GHG emission mitigation if the waste stream is better separated and send for appropriate treatment. The study on identifying the MMSW composition, which is not well documented as well as the potential treatments and savings could provide better insight for effective waste management. The opportunities for energy recovery from MSW in Europe have also been underlined by Scarlat et al. (2018).

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This study aims to evaluate the waste composition and the potential carbon emission footprint (CF) reduction through the recovery of bio-waste in MMSW for the EU-27. The baseline scenario of this study is not to the landfill but a combination of landfilling and incineration, reflecting the current treatment practice of each EU-27 countries. The novelty or significant contributions of this work include: (i) identifying the biowaste fraction by the regression model, (ii) evaluating the potential CO_2 emission reduction through incineration, anaerobic digestion (AD) and composting (iii) considering the avoided emission from the recovered product/utility in estimating the net CO_2 emission in the EU-27.

Table 1: The share of biowaste in MMSW reported in different sources

Countries	Biowaste Fraction (%)	Reference
Austria	14.50[a]; 20.50[b]; 37.60[b]	Novák (2019)[a]; Vogel et al. (2009)[b]
Denmark	46.57[c]	Edjabou et al. (2015)[c]
Finland	42.80[d]; 48.40[e]	Liikanen et al. (2016)[d,e]
France	11.50[f]	Bayard et al. (2018)[f]
Germany	21.80[g]; 21.80[h]; 28.10[i]; 31.23[j]; 38[k]; 42.80[l]	Landratsamt Kitzinger (2013)[g]; Siepenkothen (2015)[h]; Kem (2010)[i]; Sabrowski (2015)[j]; KAW Landkreis Hameln-Pyrmont (2017)[k]; Novák (2019)[l]
Greece	39.20[m]	Gidarakos et al. (2006)[m]
Italy	31.70[n]	Affidavot (2017)[n]
Luxembourg	30.42[o]	Beyer and Kramer (2016)[o]
Netherlands	39.80[p]	Cornellisen et al. (1993)[p]
Poland	40.50[q]	Boer et al. (2010)[q]
Romania	67[r]	Pop et al. (2015)[r]
Sweden	33[s]	Petersen et al. (2002)[s]

2. Method and case study

The amount of biowaste in the MMSW is estimated by a regression model, as described in Section 2.1, where different socioeconomic factors are considered. Bio-waste corresponds with catalogue number 20 02 01 is defined as garden waste and other biodegradable waste which is separately collected. In this study, biowaste is defined as bio-component in MMSW, which is a subset of MSW. Section 2.2 depicts the case study in assessing the CF reduction potential of EU-27 through recovering/treating the biowaste portion in MMSW.

2.1 Regression model

Regression analysis is performed based on Eq(1) to assess the biowaste amount in the MMSW, as the biowaste composition is not all available in the different EU countries, see Table 1. Socio-economic data (Eurostat, 2019), including GDP, population, age, population density, expenditures, gender, life expectancies, education, income etc., served as the independent variables and applied to estimate the missing values. The resulting model fulfilled assumptions on a normal distribution of residues and their zero means. If more studies on biowaste in MMSW were found for one country, their average value is considered. There have been data from different years, but there was no apparent trend over time. All available data is deemed as part of one regression model. The regression model was considered in the form of beta regression. The reason is to limit the dependent variable within the interval (0,1).

$$y = \frac{\mathrm{e}^{x^T\beta}}{1 + \mathrm{e}^{x^T\beta}} \tag{1}$$

Where y variable is seeking corresponds to the percentage of bio-waste in MMSW, x is an independent variable vector, β is regression parameter vector, T stands for transpose and e is exponential. Mentioned socio-economic data are used in this model as independent variables.

2.2 Case study

This presented study is focused on evaluating the CF reduction potential in the EU-27 countries. Figure 1 shows the amount of biowaste in MMSW predicted based on Eq(1) and the estimation of existing share in biowaste treatment (incineration) and disposal (landfill) according to Eurostat (2019) for MSW. A total of 18 independent variables were considered for the regression model, but only two, women's life expectancy and masculinity index were found significant. Respective β parameters equal to 21.39102 (intercept), -0.13303 (women's life expectancy) and -0.10653 (masculinity index). These factors are possible to describe 36 % of the variability in the data. The mean average percentage error equals to 28 % when comparing real data (average value of the country) with the model. The high variability is due to the smaller number of studies that have been done in different locations of the country. However, analyses are increasingly conducted, and it will be appropriate to update the regression results in the future.

Three scenarios are assessed in determining the potential of CF reduction through waste recovery:

- Scenario 1: Landfilled biowaste from MMSW being incinerated in the waste to energy plant.
- Scenario 2: Landfilled biowaste from MMSW treated in the biogas plant – AD.
- Scenario 3: Landfilled biowaste from MMSW treated at the composting plant.

The underlying assumption of this assessment are (i) the biowaste fraction in MMSW is separated (ii) there is sufficient capacity for the treatment transition (from landfill to Scenario 1,2, or 3) (iii) the separated biowaste fraction is suitable composting as in Scenario 3 (Risse and Faucette, 2009). The CO_2 emitted by landfill, incineration, AD and composting were assumed to be 568 kg CO_2/t, 386 kg CO_2/t, 228.5 kg CO_2/t and 26.3 kg CO_2/t of waste, as stated in Fan et al. (2020). The net CO_2 emission is calculated by subtracting the emitted CO_2 by avoided CO_2. The carbon emission intensity (g/kWh) (EEA, 2018) from the recovered energy is used to calculate the emission saving. It depends on the energy mix of EU countries. The avoided emission by composting is calculated based on the nutrient recovered from compost as described in Fan et al. (2019).

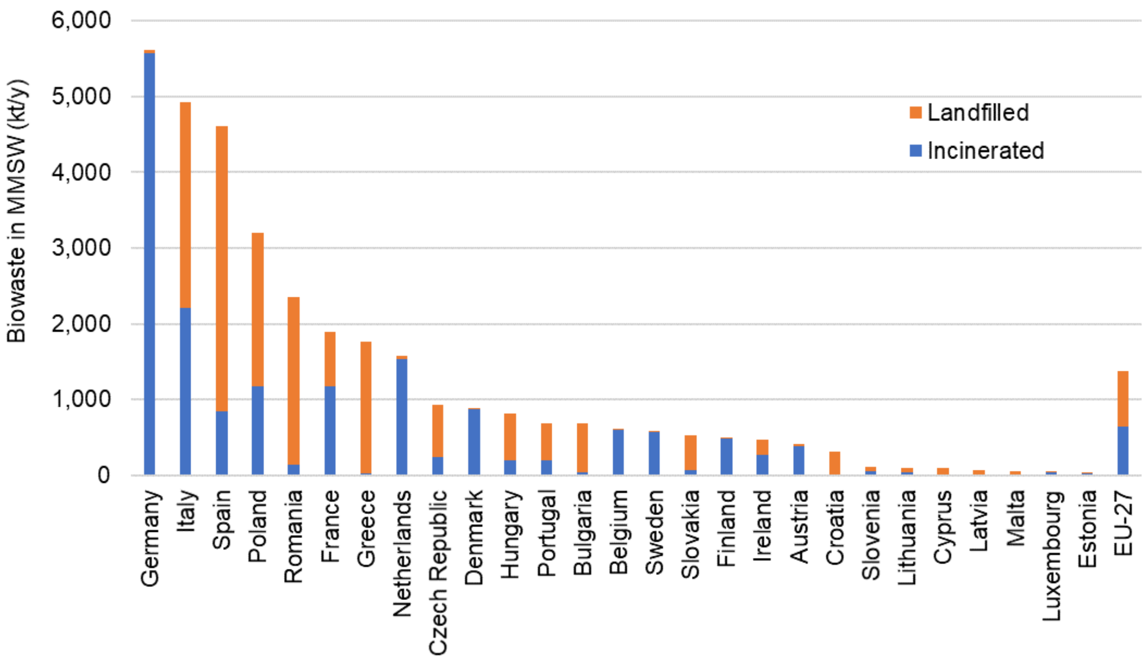

Figure 1: Estimated amount and ratio of treatment methods for bio-waste in the MMSW

3. Results and discussion

Figure 2 shows the total emitted, avoided and net CO_2 emission in the EU-27. The result indicates that none of the countries is currently at carbon-neutral (net CO_2 = 0). By referring to Figure 1, Germany generated the highest amount of biowaste, and the emitted CO_2 of waste treatment is higher than the average of the EU. However, as a high fraction is treated via incineration, the net CO_2 is comparatively lower, at 1,400 kt CO_2/y (Figure 2). For example, compared to Italy and Spain with a net CO_2 of 2,216 kt CO_2/y and 2,396 kt CO_2/y. The total net CO_2 emission of the EU, based on the current treatment methods (landfill and incineration), is 14,338.6 kt.

Figure 3 shows the CO_2 emission performance of the EU-27 average when the originally landfilled biowaste is recovered through incineration (Scenario 1), AD (Scenario 2), and composting (Scenario 3). The CF of EU-27 can be potentially reduced by 35 – 74 %. The potential CF reduction of composting is high; however, it should take note that the result can be different if the other type of emission, e.g. N footprint, is considered. The primary CO_2 saving in composting is contributed by the compost produced, which reduces the use of chemical fertilisers. The 74 % of reduction cannot be achieved if the compost is solely applied for as soil amendment, which is currently the case where most of the farmers prefer chemical fertiliser over the compost. The advantage of composting over the other waste recovery technology is that the required capital cost is comparatively lower.

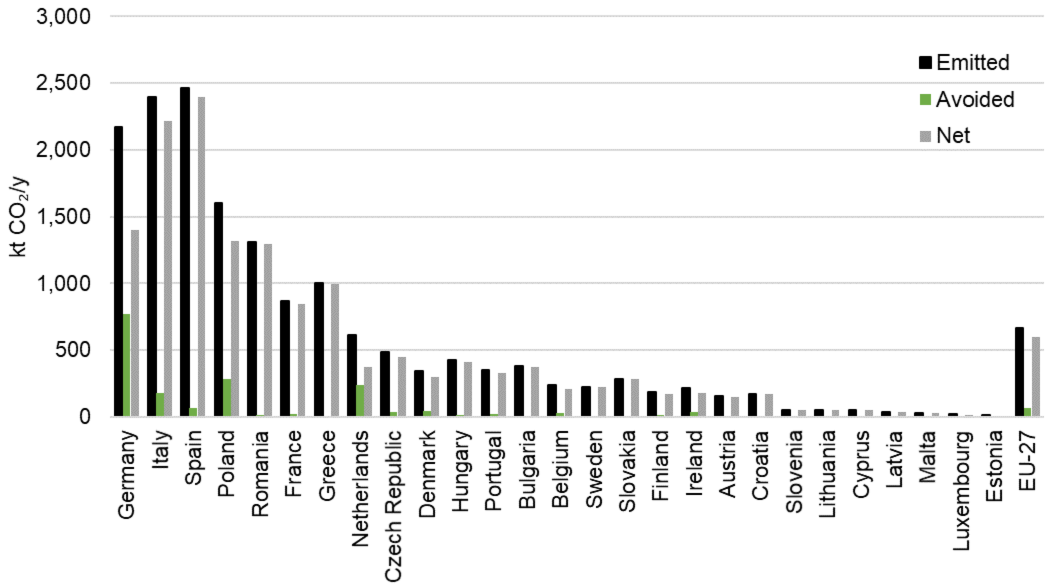

Figure 2: The emitted, avoided and net CO_2 emission in EU-27 based on the current treatment methods

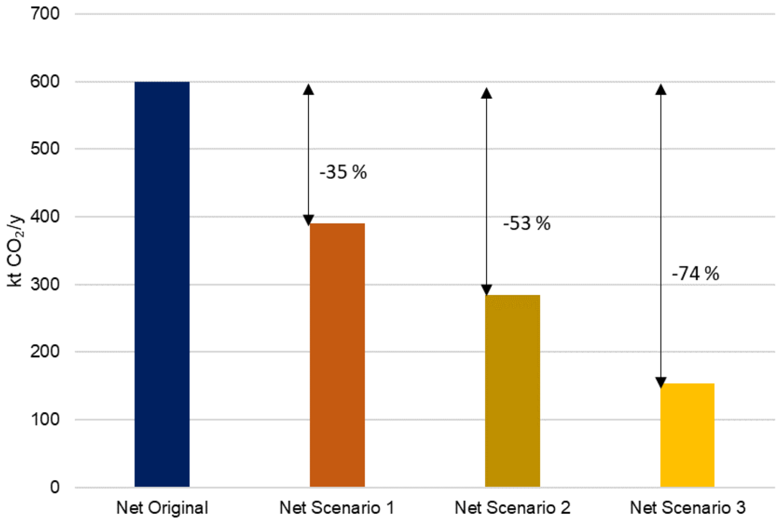

Figure 3: The average potential CO_2 reduction through waste treatment transition in the EU-27

Figure 4 indicates the potential CO_2 reduction in each of the EU-27 countries. Taking Estonia (819 g/kWh) as an example, representing the EU-27 country with a high carbon emission intensity of electricity mix, the potential CO_2 reductions are 51.67 % (Incineration), 65.98 % (AD) and 71.22 % (composting). Sweden (13.20 g/kWh), on the other hand, has a lower reduction potential (0.4 %, 0.7 % and 1.31 %). This is because the initially landfilled biowaste (in MMSW) in Sweden is low (4.8 %, see Figure 1) and the carbon emission intensity of electricity mix is low. These factors are contributing to minimal avoided CO_2 emission and low reduction potential. The highest reduction potential of 69.48 % (37 kt CO_2/y) and 91.99 % (49 kt CO_2/y) can be achieved in Cyprus through incineration and AD. It is due to the high amount of waste sent to the landfill (baseline scenario) and a high carbon emission intensity for electricity mix in Cyprus (676.9 g/kWh), as well as in Malta (648 g/kWh). The highest reduction potential, 106.78 % (32 kt CO_2/y), can be realised through composting in Malta. In some of the countries, including Cyprus, Malta, Greece, Bulgari, Romania, Croatia and Latvia, the potential CF reduction of Scenario 3 is more than 100 %. This is due to the high share of biowaste was ended in the landfill for the baseline scenario (Figure 1), which is 99.52 % (Cyprus), 100 % (Malta), 98.68 % (Greece), 94.87 % (Bulgaria), 94.32 % (Romania), 99.92 % (Croatia), and 95.93 % (Latvia), and can be converted to compost which brings the CO_2 saving through minimising the production of N fertiliser. The total CO_2 emission in the EU-27 with the implementation of the waste treatment transition is 9,202 kt CO_2 for Scenario 1, 6,790 kt CO_2 for Scenario 2 and 3,975 kt CO_2 for Scenario 3; compared to the original treatment approaches which releasing 14,338.6 kt CO_2.

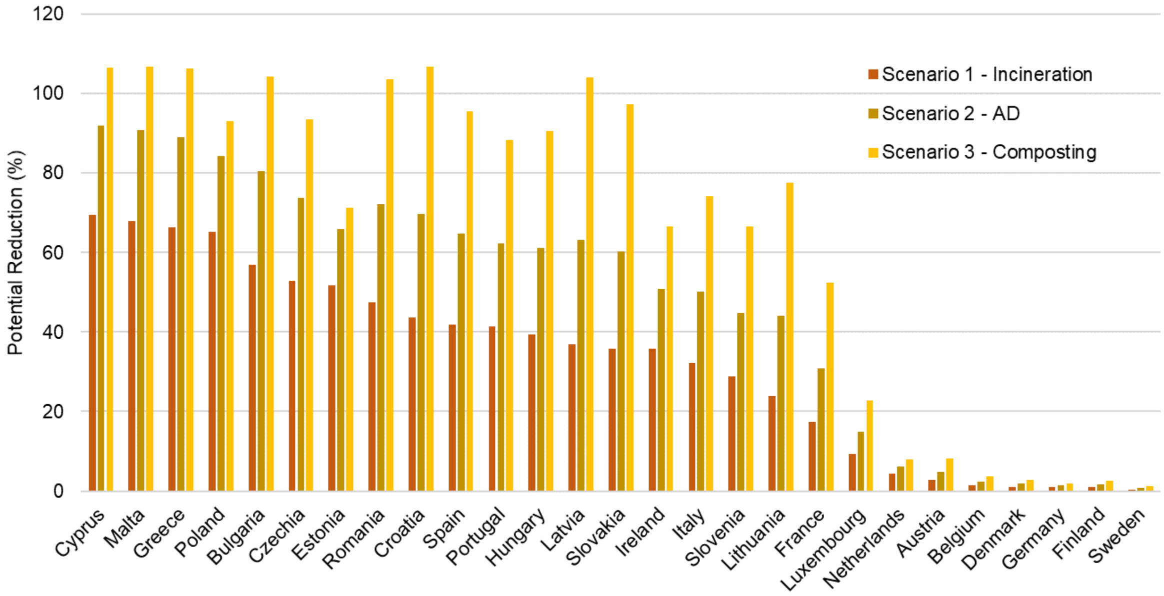

Figure 4: The potential CO_2 reduction through waste treatment transition in the EU-27

4. Conclusion

This study identifies the biowaste fraction in MMSW for EU-27 and estimates the potential CF reduction through waste recovery. The potential reduction in the EU-27 is suggested to be ranging from 35 – 74 %, can be translated to 5,137 kt CO_2/y – 10,364 kt CO_2/y. Composting offers the highest reduction potential in all the assessed countries. However, this result has to be further investigated as the composting practice is not suitable in all places, depending on the resources, infrastructure, compost demand and application standard. The land, nitrogen and water footprint, as well as the compost demand, have to be carefully evaluated. The highest reduction potential of 69.48 % and 91.99 % can be achieved in Cyprus through incineration and AD. The highest reduction potential (106.78 %) through composting can be realised in Malta. This study suggests the essential to do waste sorting to ensure the quality of the substrate and ease the waste to resources transition towards a lower CF waste management.

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