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Impact of Recycling Targets on the Calorific Value of Residual Waste Stream in Scotland

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Authors' contributions

This work was carried out in collaboration between all authors. Author ES designed the study, wrote the protocol, wrote the first draft of the manuscript and supervised data collection. Author OG collected the data and managed the literature searches. Author AD carried out the statistical analysis of the data and presented the results. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

The UK's waste management had greatly changed due to the influence of the European Union (EU) waste hierarchy that gives preference to waste recycling and thus keeps Energy from Waste (EfW) next to recycling. In addition, the European Commission (EC) demanded its member states to comply with its framework targets associated with waste recycling and landfills with waste. Responding to the EC requirements, the UK increased its recycling rate over the past years through potentially improved recycling regimes. This had resulted in significant changes in the feedstock to EfW plant characterized by its Calorific Value (CV). This research focused on developing a model to test the impact of recycling on the Calorific Value (CV) of residual waste for energy recovery. The Municipal Solid Waste (MSW) composition and the Zero Waste Plan in Scotland was used as case study under various recycling scenarios such as 50% recycling of food waste, paper/cardboard, plastics and glass. Results indicated that increase in the recycling targets resulted to a significant impact on the CV of the residual MSW. Recycling food wastes and glass did improved the CV of residual waste to 9.93 MJ/Kg and 8.20 MJ/Kg respectively with corresponding recycling rates of

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48% and 61% respectively. Further, outcomes did indicated that plastic and paper material recycling gave a negative impact on the CV and revealed that such negative effect of plastic and paper recycling could be compensated by increased food and glass recycling strategies.

Keywords: Calorific value; energy from waste; municipal solid waste; landfill; Zero Waste Scotland.

1. INTRODUCTION

The European waste directives that the society move towards being a high recycling and resource efficient society, has greatly influence the trends in the UK waste management over the past fifteen years. Arguably, one of the most influential policy has been the EU Landfill Directive (99/31/EC) targets, which demands the UK to reduce its amount of Biodegradable Municipal Waste (BMW) sent to landfill with penalties of up to £180 million per year for non-compliance [1]. This policy has led to a great extent an attitudinal change and spectacular improvement on the health and wellbeing of the environment and subsequently of mankind.

This attitudinal change towards waste management is increasingly centred on the EU waste hierarchy that treats waste as a resource and gives priority to waste prevention followed by recovery, recycling and disposal. In essence, the UK Government has develop an efficient waste management strategy that gives prominence towards its overarching mission of transition to a green economy and to comply with the EU targets. As a result, there has been a significant reduction in the quantity of waste sent to landfills with significant improvement in the recycling skills in waste management. According to [2], the share of Municipal Solid Waste (MSW) used in landfills in the UK has greatly reduced from 80% in 2001 to 49% in 2010 and the recycling rate has increased from 12% in 2001 to 39% in 2010. In recent times, growing trend in waste recycling has put pressure on the pursuit of additional recycling of materials such as food waste, paper, plastic and glass.

In considering cost of recycling, the cost of collection, sorting and pre-processing of wastes is potentially higher in comparison to the energy recovery from it; high recycling rates can only be achieved at high cost [3]. Even though the cost of recycling is higher than that of the energy recovery, it has been given top priority in the waste hierarchy. Thus, the energy recovery remains second to recycling in the UK.

It should be noted that Energy from Waste (EfW) does not only supports reduction in the volume of waste stream, but also provides a source of electricity and heat. According to Ofgem [4], the ongoing development in EfW with appropriate technologies such as incineration, gasification and pyrolysis across the UK are eligible for Renewable Obligation Certificates (ROC) as it has the potential in supporting the UK's renewable energy targets. The EfW technologies recover energy through thermal degradation of waste composition and the magnitude recovered is underpinned by the Calorific Value (CV) of the waste composition. Along with the social, economic and demographic factors, the composition and quality of the residual stream for energy recovery is also highly influenced by the increasing national UK recycling targets and moisture content contained within the waste.

As the UK focus more on recycling BMW and target materials with high calorific value, it will have significant impact on the CV of the residual waste sent for thermal treatment. For instance, an increase in recycling of hydrocarbon-based products like plastic, paper and glass will have a negative impact on incineration facility with priority on energy recovery as a result of reduced CV of the residual waste (Koufodimos and Samaras, [5]. These uncertainties over the residual composition of municipal waste materials that results in technical difficulties due to the impact of increased recycling activities, may affect the investor's confidence over the EfW facilities being built in the UK and subsequently affects the overall renewable energy capacity from EfW plants and waste export market in the UK.

This research explores the impact of recycling residual MSW stream using Scotland's MSW and Scotland's Zero Waste Plan statistics of 2011 as a case study and tested under different recycling scenarios which includes: The UK's waste management background, EfW capacity, technologies and trend in the waste export as a fuel to other European countries. To this extent, the aims of the study were to develop a model to test the impact of recycling targets on the Calorific Value (CV) of Scotland's residual stream and to explore the context relating to Waste Derived Fuel (WDF) in the UK. The specific objectives therefore were:

i. To develop a model to test the impact of recycling on the CV of Scotland's residual stream, when more recycling of materials such as food, paper, plastic and glass are utilized.
ii. To evaluate the influence of recycling on the CV of the residual stream to Energy from Waste (EfW) plants.

2. METHODOLOGY

2.1 Data Collection

Scotland's MSW statistic data was for the year 2010/11 and Scotland's Zero Waste Plan was used as case study to test the impact of recycling on the CV of residual waste. Scotland's local authority do collect data on the quantity of MSW sent for recycling to the Waste Data Flow (WDF) website. Waste Data Flow is an online web-based system that produce statistics for waste collection and management in the UK [6]. All information recorded into WDF database comes from the data provided to local authorities by their waste contractors. Notably, the Scottish local authorities started using WDF online statistics from 2006 to report data on waste generated, recycling and disposal [6].

2.2 Allotment of MSW Composition Data

Some apportionment were made on the waste composition data obtained from the WDF database and entered into a model developed for this study in order to estimate the impact of recycling on the CV of the Scotland's residual waste. Data for composition of Scotland's MSW in 2009 were published by Zero Waste Scotland in 2010, in which the overall composition of recycling/composting stream and waste generated were categorized into 24 materials with the recycling rate of 32.5% [7]. Since the data published in 2010 for recycling had increased, data from the Scotland's MSW composition for 2011 were obtained from the WDF database and the result was updated.

In addition, it was observed that the composition category of MSW between WDF and Zero Waste Scotland database did vary and it was necessary to reduce the materials into a common set category. Thus, the materials in the composition category of the Zero Waste Scotland (24 materials) and Waste Data Flow (WDF) database (53 materials) were grouped to form a common set of material category (15 materials) for this study. Appendix 1 showed the grouping methodology used in this study for paper/ cardboard materials apportionment and same procedure was used for the apportionment of other materials from the Zero Waste Scotland and WDF database to form a common set of material category.

Data for total waste generated under each category differs due to the apportionment therefore, in order to find the total waste generated under each category, the total MSW generated tonnage reported in 2011 by WDF database was approximated with the apportioned composition category taken from the waste compositional data in Zero Waste Scotland report of 2010.

2.3 Estimating Residual MSW, CV and Current Recycling Rate

After defining quantity sent for recycling and total waste generated under each apportioned category, the residual MSW defined as the quantity of waste left after the removal of recyclable materials through recycling programmes was then calculated using Equation (1).

$$Residual\ MSW = \frac{Total\ Waste\ generated - Quantity\ Sent\ for\ Recycling}{Composting} \quad (1)$$

Then, the current recycling rate of the MSW and CV of the residual MSW were identified by using Equation (2) and (3) respectively.

$$Recycling\ Rate\ (\%) = \frac{Quantity\ sent\ for\ recycling/composting}{Total\ MSW\ Generated} \times 100 \quad (2)$$

$$CV\ of\ Residual\ MSW = \sum_{i-1}^{15} Tonnage\ of\ Residual\ Material_i \times CV_i \quad (3)$$

Where, *i* is the material category and CV_i is the Calorific Value (CV) of the individual material.

2.4 Testing Scenarios

In order to test the impact of recycling on the CV of the Residual MSW, a number of scenarios were chosen and are justified below.

2.4.1 Case A: 50% recycling of food waste

In Scotland, it was reported that about 2.1 Mt of food waste were produced annually. And the action plan reported in the Zero Waste Scotland programme for 2012-15 was to implement food waste collection schemes to cover 0.5 million households with a target of 70% participation rate by 2016 [8].

Further, it has been decided to increase the collection of dry recyclates and food waste from commercial sector and also plan for 150,000 tpa additional food waste processing through AD and IVC to produce compost and divert 360,000 tpa of BMW from landfill [8]. All these plans gave priority to food wastes being collected extensively across Scotland to achieve the Scottish Government target of 50% and 60% recycling of household waste by 2013 and 2020 [7], which will significantly increase the food waste recycling rate and influence the CV of residual stream used for energy recovery. Thus, the scenario of 50% recycling of food waste was selected and tested under Case A.

2.4.2 Case B: 50% recycling of paper/ cardboard

Article 11 of the EU WFD, demand its member of state to prepare for reuse/recycle 50% of the materials such as paper, plastic, metal and glass from household by 2020 [9]. Even though paper/ cardboard materials were already existing in the recycling programmes, nearly 263 Kt of paper/ cardboard materials were still remaining in Scotland's residual stream after current recycling [6]. Hence there was the urge to improve paper recycling rate to meet the EU WFD targets. Thus, an assumption of 50% recycling of paper/ cardboard materials was selected and tested under Case B.

2.4.3 Case C: 50% recycling of plastic

A raising opposition for combustion of fossil fuel based products at ATT plants in addition to the EU WDF demand towards preparing 50% recycling of plastic from households by 2020 [9] influence an extensive reuse and recycling of plastic materials across the UK. Plastic is a fossil fuel based material with higher CV in comparison to other materials in the waste composition. Further to this, the action plans reported in the Zero Waste Scotland programme plan for 2012-15 was to increase the capacity for plastic reprocessing between 2012 to 2013 and provide incentives for closed loop plastic recycling and to stimulate demand for recycled plastic in the manufacturing sector [8]. The raising trend in plastic recycling and removal of such higher CV material in Scotland is likely to have a potential impact on the CV of residual stream for energy recovery. To this end, a scenario of 50% recycling of plastic was assumed and tested under Case C.

2.4.4 Case D: 50% recycling of glass

In Scotland, nearly 248,000 tonnes of glass wastes were generated from households every year and it is equivalent to 8% of the total waste generated [8]. Due to the influence of the EU WFD and Scotland Waste Regulation 2012, glass materials were extensively collected across the UK. In addition, WRAP estimated that recycling rate of packaging containers had reached 60.7% in 2012; the UK had a better glass collection and recycling rate in comparison to other European countries [10]. This demonstrated an increasing trend in the glass recycling. Even though glass is a relatively inert material with low CV, its removal from residual waste composition by the recycling programmes will have a significant impact on the CV of the residual stream for thermal treatment. Thus, a scenario of 50% recycling of glass material was selected and tested under Case D.

2.5 Calculation Methods

For Case A, it was assumed that 50% tonnage of food wastes present in the residual stream was recycled and its CV was calculated by using Equation (3). The equivalent recycling rate was calculated by using Equation (2). In Case B, it was assumed that 50% of the tonnage of paper/ cardboard were recycled from the residual stream. Likewise, its equivalent recycling rates and CV were computed using Equation (2) and (3) respectively. The same procedure were used for Case C and Case D respectively to obtain a cumulative effect.

3. RESULTS AND DISCUSSION

The impact of recycling on the CV of Scotland's MSW Stream is presented in Fig. 1.

The Fig. 1 shows the results obtained from various recycling scenarios assumed in the study to test the impact of recycling on the Scotland's residual stream. The current recycling rate (2011) for Scotland's MSW was estimated

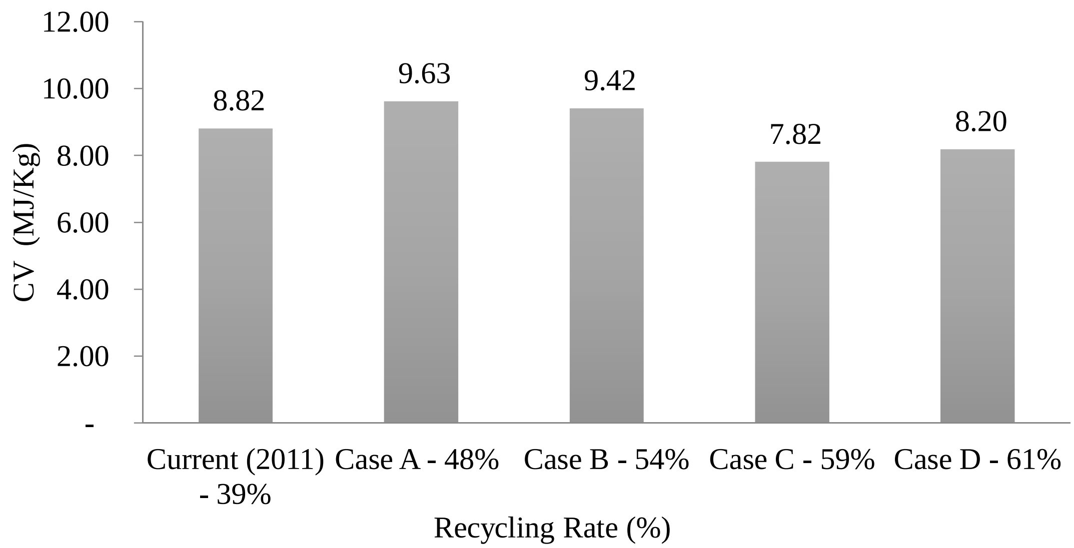

Fig. 1. Impact of recycling on CV of residual waste

as 39% with a CV of 8.82 MJ/Kg and when no recycling action was carried out the CV would be 7.95 MJ/Kg. For Case A, when 50% of the food waste is recycled the recycling rate reached 48% with an increased CV of 9.93 MJ/Kg due to reduced moisture content in the waste stream. In addition, the potential increase in the recycling rate from 39% to 48% indicated that food waste is dominant in Scotland's residual composition. Results from the Case A indicated that removing food waste from residual waste composition did increase the CV. This result agrees with the report by [11] associated with residuals heating value as a function of waste component recycling.

Additionally, since the bio waste content is eligible for PAS 100 accreditation, its removal or separate collection will benefits to the waste management companies. Further, the thermal treatment removal of food waste tend to less moisture to drive off combustion so there could be less of an energy cost associated with using residuals as a fuel for energy recovery. Therefore, increase in the food waste recycling will lead to a positive impact on the CV of the residuals for thermal treatment and significantly increase the recycling rate which will potentially help in achieving the EU and Scottish Government recycling targets.

For Case B, when 50% of the paper / cardboard material were removed through recycling schemes, the recycling rate was increased from 48% to 54% and the CV dropped slightly from 9.63 MJ/Kg to 9.42 MJ/Kg which indicated that increasing paper/cardboard recycling will not lead to an increase in the CV of EfW but rather lead to an insignificant decrease in the CV of the residual stream. This is in agreement with the estimation made by [11] which indicated that there were only 4.2% drop in the CV of residual stream for 100% recycling of paper materials.

Even though the residual tonnage of paper/cardboard materials (416 Kt) were higher in comparison to plastic materials (273 Kt), it does not brought about any significant change in the CV of the residual stream perhaps due to the low CV of paper / cardboards in comparison to plastics. Therefore, increasing recycling effort of paper / cardboard materials may not bring significant impact on the CV of the residuals for energy recovery in Scotland.

In Case C, 50% recycling of plastic materials reflects a dramatic fall in the CV of the residuals. Plastics have lowest recycling limits but yet tend to be dominant variant of the CV and thus when plastic recycling rate improves, it will have a potential negative impact on the CV of the residual waste for thermal treatment. It is obvious from Fig. 1 that as the recycling rate of plastic increased to 50%, there was a drop in the CV from 9.42 MJ/kg to 7.82 MJ/Kg due to the removal of relative proportion of the high CV plastic materials from the residual composition in the recycling regimes. In addition, recycling rate also increased from 54% to 59% due to low percentage of plastics in the residual composition. This result is in consonance with a report by [12] that an increase in the relative proportion of plastic will increase the CV of the residual stream and vice versa.

It is therefore obvious that even for a slight increase in the recycling of plastic materials, there will be a significant drop in the CV and directly influence the viability of the residual stream as a feedstock for energy recovery. Since plastic is relatively a fossil based product, strong arguments were made against combustion of such non-renewable resource at thermal treatment plants for energy recovery. In addition, use of residual stream with higher proportion of plastic materials at EfW facilities means higher energy from a relative fossil based source and this may diminish the ROC criteria and consequently affects the economic value of the Waste Derived Fuel (WDF) leading to an economic loss for the EfW plant investors.

In considering Case D, 50% recycling of glass material in the residual composition had not brought about any noticeable change in the CV. In this case, the CV only increased from 7.82 MJ/Kg to 8.20 MJ/Kg due to the fact that glass is a relatively inert material with low CV. On the other hand, the recycling rate in Case D slightly increased from 59% to 61% due to low proportion of glass materials in the Scotland's residual stream.

Glass can be recycled a number of times but it is relatively an inert material with low CV. Hence increasing the recycling effort of glass material may not bring noticeable increase in the CV of the residuals. However, seeing the slightly positive impact on the residuals for energy recovery, increasing recycling effort on glass wastes seems likely to increase CV of the residual stream such that more energy could be recovered per tonne. However, in practice this will not be beneficial for the EfW plant investors.

Generally, results obtained from the various scenarios (Case A - D) to test the impact of recycling were in agreement with the findings of [13] and [14] that 50% recycling of packaging materials such as paper/cardboard, plastic and glass will lead to 8% reduction in the Net CV of the residual MSW while separate collection of organics, paper, metal, wood, and textiles will result in an increased lower heating value (LHV) due to the progressive concentration of plastic and low moisture content. Additionally, an increase in the recycling of food waste and glass from the residual wastes may results in a significant increase in the CV due to reduced moisture content and consequently increase the recycling rate due to its higher proportion in the residual composition.

On the other hand, reduction in the quantity of residual waste due to increased recycling activities may create competitive situation in the market and tend to cause companies to compete for smaller share of waste. Further, new built EfW plant requires some advanced combustion technologies to confront uncertain feedstock composition and its resultant CV generated from recycling activities. This will increase the operational cost and influence investor's confidence over EfW plants.

In addition, reports associated with the UK's waste management capacity need by [15] and [16] have mentioned a capacity gap. Thus, uncertainties over the feedstock, CV and impact on investor's confidence will act as barrier in developing EfW plants across the UK, increase the waste exports to European countries and strongly influence path in achieving the renewable targets of the UK Government.

Hence it is beneficial to locate EfW plants nearer to large urban region to ensure sufficient inflow of feedstock. But in the UK, there are strong oppositions for sitting EfW plant near urban centers due to pollution concerns from thermal treatment plants. However, according to [17], there is a sharp decline in the toxic pollutants from thermal treatment plants over the past years. Notwithstanding, it is recommended that an EfW facilities should be installed with necessary modern abatement technologies to avoid future conflicts. Further, region that engages a separate collection of bio waste could be more suitable to improve efficiency of the EfW plants. Therefore, Zero Waste Scotland plans towards improving food waste and glass recovery will bring a positive impact on the CV of the residual stream for energy recovery and simultaneously improves the recycling rate.

When no recycling is carried out, then the CV of Scotland's MSW would be 7.95 MJ/Kg as it is mentioned in the EU waste hierarchy that energy recovery is given importance only when recycling is exhausted. Hence it is not possible to combust all the collected waste for energy recovery. However, negative effect of the plastic and paper recycling on the CV of the residuals can be compensated with increase in recycling of both food and glass wastes which will significantly increases the CV of the residuals MSW for energy recovery along with an increased recycling rate. Therefore, it is best to direct a waste composition with low food and glass waste for energy recovery. To this end, it is possible to increase the CV of the residual waste without affecting the recycling rate and the EU waste hierarchy. Thus, a high level of recycling and energy recovery from waste can co-exist in the UK as evidenced from [18] statistics associated with MSW management in the EU.

4. CONCLUSION

Development of the model to test the impact of recycling on the CV of Scotland's residual stream indicated a negative impact on the CV, when more recycling of paper/cardboard and plastic materials are carried out. In contrast, results from the model indicted a positive impact on the CV when there were increased recycling of food and glass wastes. This indicated that an increase in the recycling of food waste and glass material will significantly increase the CV and provide positive impact on the residuals for thermal treatment. Thus, it is recommended that an increase in food and glass waste recycling ratio in comparison to that of plastic and paper/ cardboard recycling should be encouraged.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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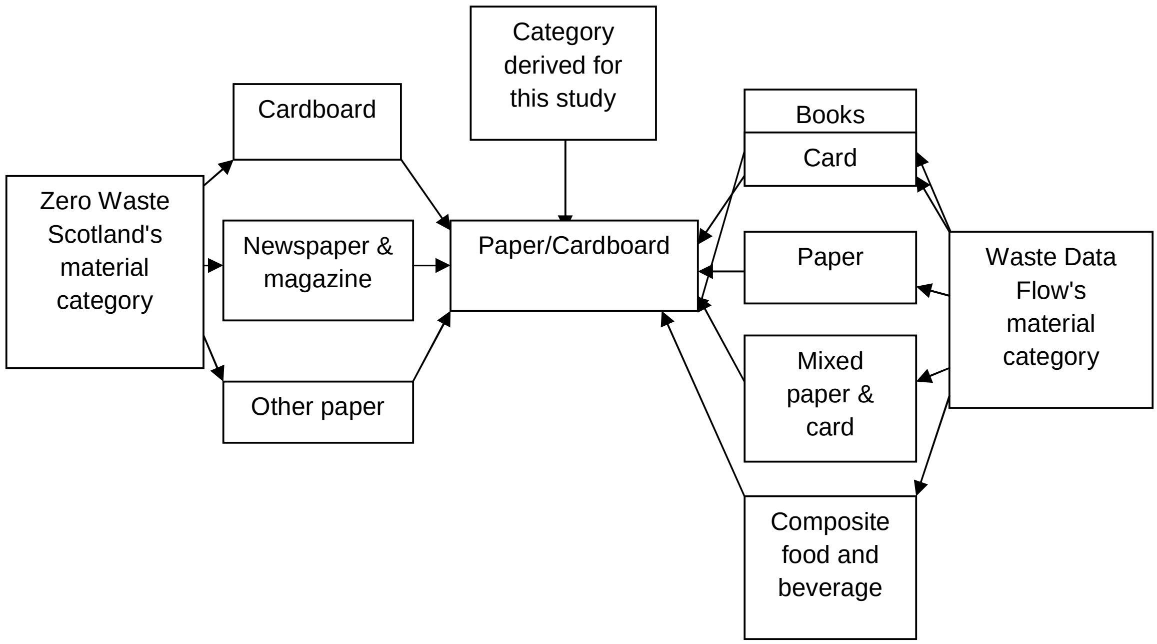
APPENDIX



Appendix 1. Apportionment of the paper / cardboard material categories

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