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Leading the World: A Review of Household Recycling in Wales

Ian D. Williams * and Joseph Phillips

Faculty of Engineering and Physical Sciences, University of Southampton, University Rd., Highfield, Southampton SO17 1BJ, UK; jrp1g19@soton.ac.uk
* Correspondence: idw@soton.ac.uk

Abstract: Wales is one of the world leaders in household waste recycling with a steady recent recycling rate of ~65%. The Welsh Assembly Government (WAG) set a statutory target of achieving a 70% recycling rate by 2024/25. We reviewed historical trends in waste management in Wales from 2006 to 2020, with a focus on recycling. Authoritative, official data were obtained from WasteDataFlow, an Internet system for municipal waste data reporting by UK local authorities to government. Data are collected quarterly allowing the generation of time series plots, trendlines and like-for-like comparisons between groupings of various characteristics, such as number of separate kerbside collections, income, political preference, and impact of policy changes. Results showed that the approach taken by the WAG to politically prioritise and encourage participation in household recycling has achieved impressive results that contrast starkly with the recycling performance of other UK countries. In Wales, household waste disposed annually per person via landfill decreased from ~410 kg to <50 kg and household waste recycled increased from to ~150 kg to ~310 kg, with a recent increase in incineration with energy recovery to ~135 kg as infrastructure has come online. Recycling rates show a seasonal variation due to increases in garden waste sent for composting in the summer. There are variations in local authority performance across Wales, mainly caused by variations in the number of separate collections. Co-mingled collections tend to lead to higher contamination of recyclates that are then not able to be sold for recycling. Deprivation, as indicated by differences in income, also influences total waste arisings and recycling rates. A plateau of ~65% recycling rate was reached in 2020, with incineration reaching a rate of >25%. The recycling rate plateaus at exactly the same time as incineration comes on stream. Evidence demonstrates that improvements to recycling rates can become more difficult when incineration becomes available. Whilst further reductions and improvements to recycling in Wales will be more challenging, the WAG's track record of focused proactive political and policy support shows what can be achieved when there is suitable political will. The WAG has demonstrated that it tends to deliver on its waste-related plans, and it clearly has the best chance of any of the UK's four countries of achieving its aims.

Keywords: municipal waste management; time series; recycling; political support; policy; circular economy

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1. Introduction

Disposal via landfill has historically been the dominant method of municipal waste treatment and disposal in the European Union (EU). The EU's Waste Framework Directive of 1975 (Council Directive 75/442/EEC) introduced the waste hierarchy into European waste policy for the first time, emphasising the importance of waste minimisation. Implementation of the waste hierarchy was optional to member states; but there was an expectation that it would be included within national waste management legislation. The waste hierarchy is a guiding principle that gives top priority to preventing waste; when waste is created, it gives priority to direct re-use, recycling, recovery methods, such as energy recovery, and last of all disposal (Council Directive 2008/98/EC). However, in

practice most countries have viewed the hierarchy as a "ladder" and have sought to climb it step-by-step from the bottom (landfill) to the top (waste prevention). In fact, there is nothing to stop countries heading straight for the top, skipping multiple steps in one bound.

Due to the ongoing high levels of landfilling across the EU in the early 1990s, and apparent lack of adherence to the waste hierarchy, diversion of municipal waste from landfill became a priority [1] and was legally addressed in 1999 by the EU's landmark Landfill Directive (Council Directive 99/31/EC). Specific targets were not set for the overall reduction in disposal via landfill but for the amount of biological municipal waste sent to landfill; by 2020, less than 35% of 1995's biological municipal waste tonnage must be landfilled (Council Directive 99/31/EC). Other EU Directives reinforced the desire to move towards more sustainable resource use and protection of the environment via application of the waste hierarchy. Perhaps the most significant directive is the EU Waste Framework Directive, introduced in 2008, which set an objective that 50% of all municipal solid waste was to be recycled, or composted, by 2020 (Council Directive 2008/98/EC).

However, despite all this legislative activity, there was no guarantee that these targets would be met. In fact, widely different combinations of materials recycling, composting, incineration with energy recovery and the landfilling of residues are utilised for the delivery of waste management across the EU [2]. It has been widely reported that Wales is the second best country in the world at municipal waste recycling, just behind Germany and just ahead of Singapore [3]; this report reviews in detail at why countries achieve their particular recycling rates. The combination of methods used by countries depends upon many factors, including the availability of space, finance, technology, workforce skills and infrastructure, and political willingness to proactively implement the principles of the waste hierarchy.

In the United Kingdom (UK), waste policy is a devolved matter. Political factors that have been shown to have a key influence on solid waste management have been identified as including government stability, corruption, accountability of leaders, local government plans, government priorities, influence of politicians and level of bureaucracy [4]. The devolved administrations of England, Scotland, Wales, and Northern Ireland are each responsible for setting their own waste strategy and policy. They have generally focused on improving recycling, mainly because recycling is an obvious way to facilitate a transition to a circular economy and a more resource-efficient society [5]. Whilst the core focus of these strategies has been on ensuring national compliance with EU directives, Scotland and Wales have typically chosen to be bolder than England and Northern Ireland by taking ambitious approaches that often exceed the EU's requirements [6]. For broader context, Sections 1.1–1.4 provide a brief critical review of each country's strategic and political approach to waste management and recycling since 2010.

1.1. Waste Management in England

The recycling rate in England reached 40.3% in 2009/10. Here, the national government aimed to be a "zero waste economy" by 2020 by recognising waste as a resource in-line with the waste hierarchy and to reduce greenhouse gas (GHG) emissions. However, whilst the *Waste Management Plan for England 2013* aimed to establish a path towards a "zero waste economy", it did not include any new waste management policies for England. The government adopted a relatively *laissez-faire* approach to waste regulation and policy in England and only a small number of government-led initiatives were anticipated. These included a plan to improve the quality of recyclates produced at materials recycling facilities, promotion of waste prevention and reduction efforts, and the introduction of a policy for the delivery of major energy infrastructure, including new energy from waste installations (principally advanced thermal treatment technologies). There was a commitment to enhancing the role of anaerobic digestion (AD) in England, with AD recognised as being an effective means of reducing GHG emissions from waste management and supplying renewable energy. Overall, English waste strategy and regulation was chiefly driven by use of the Landfill Tax escalator—an environmental tax designed to help reduce the amount of

waste going to landfill—local initiatives and government-issued recycling targets for local authorities. English local authorities were given flexibility in deciding how to meet their targets and the government stated that it would only intervene in waste matters where necessary or where there is a clear market failure. To illustrate, here is a direct quote from the responsible minister, Eric Pickles, from a contemporary newspaper article [7]:

> *"If you want people to do something, then it's always much more effective to give them support and encouragement—a nudge in the right direction—than to tell them what to do and then punish them if they don't obey. Recycling is a case in point. We all recognise that we've got to cut down the amount that gets dumped in landfill. The previous government planned to do that in the most heavy-handed way possible: with bin taxes that would hit people in their pockets with exorbitant fines, enforced by an army of bin bullies to snoop through people's rubbish. In all likelihood, this would have just fuelled fly-tipping, backyard burning and more trips to the dump as people tried to avoid paying the tax."*

This hands-off approach failed dismally, as predicted by Farmer et al. [8]. England did not meet its target to recycle 50% of household waste (known as "waste from households") by 2020; indeed in 2020, this recycling rate was 44.0%, down from 45.5% in 2019, and just 4% higher than a decade earlier. The government claimed that targets were missed because of the impact of the COVID-19 pandemic, and whilst this was undoubtedly a factor, it hides the long-term inability or unwillingness of the responsible ministers to proactively enact its own plans.

1.2. Waste Management in Northern Ireland

The recycling rate in Northern Ireland was the lowest in the UK in 2009/10 at 35.2%. As a response, the (then) Northern Ireland Environment Minister (Alex Attwood) proposed a "bold new plan" to prevent waste being disposed via landfill by using planned interventions that focus only on areas where most impact could be achieved. Consequently, the national waste strategy for Northern Ireland, *Delivering Resource Efficiency*, published in 2013 set out a policy framework for sustainable management of waste. It ambitiously proposed to introduce a 60% recycling target by 2020 for LA collected municipal waste; this ultimately defaulted to the EU's 50% target. The strategy emphasised the need to view waste as a resource, with landfill diversion recognised as the key driver and contained specific targets for municipal solid waste management by 2015 and 2020. Recycling targets for specific waste streams were in line with those of the EU Directive on Packaging and Packaging Waste (94/92/EC). In September 2014, the Northern Ireland Executive released its National Waste Prevention Programme, *The Waste Prevention Programme for Northern Ireland—the Road to Zero Waste*, which outlined a strategy to reduce waste arisings, improve resource efficiency and emphasised the need for a whole life cycle approach in evaluating resource management solutions.

Northern Ireland first met its recycling rate target in 2018/19, although it fell back to 50% in 2020/21 from a high point of 51.1% in 2019/20.

1.3. Waste Management in Scotland

The recycling rate in Scotland was 36.7% in 2009/10. *Scotland's Zero Waste Plan*, published in June 2010, provided Scotland's overarching, long-term policy document for resource efficiency and sustainable waste management. The document outlined the Scottish Government's long-term vision for a "zero waste" Scotland. Measures promoted in the document included a ban on landfilling of certain recyclable materials, a requirement for local authorities to separately collect certain wastes (e.g., food waste) restrictions on thermal treatment feedstock and the establishment of a 25% cap on local authority collected waste (LACW) sent for thermal treatment and measures to reduce GHG emissions from waste management. The document sets a series of targets for recycling, preparation for reuse, or composting (or AD) of LACW and a target for a maximum landfill rate of 5% of LACW by 2025. These policies and targets were legally established by the Waste (Scotland) Regulations (2012). The Scottish Government followed this up by publishing the

Scottish Household Recycling Charter in 2015 that set out a more consistent approach to household recycling collection systems. The charter was supported by a Code of Practice, also published in 2015, that aimed to increase householder participation in recycling, improve the quality of recyclate; and provide greater economic benefits and opportunities for savings in local authorities. Further actions included assistance from the Scottish Materials Brokerage Service to develop contracts to reduce risk from price volatility of recyclables and a statutory Code of Practice for Materials Recovery Facilities.

Scotland's recycling rate peaked at 45.5% in 2016 but has since dropped slowly, partially because of the pandemic and partially because of falls in paper and cardboard recycling. Despite its plans and measures, Scotland failed to meet its EU target to recycle 50% of household waste by 2020, achieving only 44%.

1.4. Waste Management in Wales

The recycling rate in Wales was just 7% in 2000/01, reaching 40.5% in 2009/10 as a direct response to the Landfill Directive (Council Directive 1999/31/EC). The Welsh Assembly Government (WAG) decided to politically prioritise and encourage participation in household recycling. It published its ambitious long-term waste strategy, entitled *Towards Zero Waste* in 2010. It set out a framework for improving resource efficiency and the sustainability of waste management in Wales until 2050. Measures promoted include waste prevention (a target of an annual 1.5% reduction in national waste arisings until 2050 is set), separate collection of food waste, the provision of information on the destinations of recyclate, kerbside sort for household dry recyclables collection (this measure is currently under review). The document set a series of targets for recycling, preparation for reuse, or composting (or AD) of LACW and stipulated that, at a minimum, 80% of waste sent for recycling, preparation for reuse, or composting (or AD) must come from source separation. Further targets included maximum levels of landfill of municipal waste, 10% in 2019/20 and 5% in 2024/25, and maximum levels of thermal treatment of MSW for individual local authorities. These policy measures and targets were legally established by the Waste (Wales) Measure 2010. Implementation of the strategy was anticipated via six key Sector Plans that described the role of each sector in delivering the outcomes, targets, and policies in *Towards Zero Waste*.

In December 2013, the WAG introduced the *Waste Prevention Programme for Wales*, which addressed waste prevention in fulfilment of the requirements of the EU Waste Framework Directive. The strategy supported *Towards Zero Waste* and outlined policies and targets to encourage waste prevention action from households, businesses, and the public sector. The WAG also established a broad and ambitious cross-sectoral sustainable development scheme, which is outlined in *One Wales: One Planet*, published in May 2009 [9]. After years of consultation, the bold policies outlined in *One Wales: One Planet* were legally established through the Well-being of Future Generations (Wales) Act 2015.

The WAG has successfully delivered its plans. Welsh councils first recycled, reused, or composted its target of >50% of municipal waste in the twelve months to December 2012 (52%). Wales's recycling rate has steadily continued to increase, recently rising from 65.1% in 2019/20 to 65.4% in 2020/21, a record high. Wales undoubtedly had tougher COVID-19 restrictions in place than England, and total municipal waste arisings dropped by 2.6% in the last year, making this achievement even more impressive.

So why has Wales been so much more successful in managing its waste than its UK contemporaries? The purpose of this paper is to critically review historical trends in recycling in Wales and the reasons for any changes to see if the WAG's distinctive approach has been successful.

2. Materials and Methods

2.1. Data Collection

Historical data for all Welsh local authorities (LAs) were secured from WasteDataFlow (https://www.wastedataflow.org/ Accessed on 4 April 2022) from 2006 onwards. Sec-

ondary data are commonly used to inform waste management studies [10]. WasteDataFlow is the official online system for municipal waste data reporting by UK local authorities to government. The system has been in use since April 2004 and researchers/organisations can register to access data.

Waste per person estimates were used to compare LAs. All 22 Welsh LAs were selected whilst also obtaining rates for all three waste streams. Mid-year population statistics were collected from 2006 to 2019 from StatsWales (https://statswales.gov.wales/ Accessed on 4 April 2022), which matches that of the timeframe was available from WasteDataFlow. Some analysis demanded a quarterly interpretation of per person values; in this case, the mid-year figures were used for every quarter of the given year. When yearly data were presented, the mid-year population was applied directly to that statistic. This analysis follows a similar concept to that used in [11].

It is important to note that WasteDataFlow changed its method of data presentation in 2012 [8]. Like all data collection systems, WasteDataFlow is subject to continual improvement and development that impacts on the way that data are entered. The nature of introducing these changes can produce data interpretation issues, such as with historic data already in the system. To ensure the best data were used in this study, contact was made, several times, with the staff from WasteDataFlow to clear any discrepancies and to acquire additional data.

The number of separate kerbside collections was recorded by visiting each LA's website and finding the residential help guide. Data were summarised using a colour-coded table that presented if a material was collected independently or if it was part of a grouping of items, which allowed for the number of separate kerbside collections to be calculated. The websites that were visited listed the time between collections, which meant that the number of weeks between kerbside waste collections could be collected.

2.2. Data Analysis

To assess the difference in recycling rates of the extreme ends of the spectrum, a comparison was made between the LAs with the four highest and lowest number of collection separations. Per person waste weights were used to enable comparisons and trendlines allowed for a clear visual representation of the changes over time. Regression equations and coefficients of determination (R^2) were calculated, and are shown on figures as appropriate, to illustrate how well the regression model explains observed data. R^2 is a statistical measure that explains to what extent the variance of one variable explains the variance of the second variable. In time series analysis, R^2 is a statistical measure of how well the regression line approximates the real values. Henseler et al. [12] and Moore et al. [13] report a widely accepted general "rule of thumb" for interpreting the strength of a relationship based on its R^2; a value of >0.7 reflects a strong effect size, a value $0.5 < R^2 < 0.7$ reflects a moderate effect size, with values < 0.3 considered as very weak or no effect size. Thus, we have adopted this general rule in our interpretation of the statistical outputs.

To obtain a representative pattern of general political preference within Wales, both the general and Senedd (Welsh Parliament) election results were recorded from 1999 to 2019. By mapping the overlap between consistency and LA borders, each constituency was listed next to every LA in which part or all of it resided. Using result for each political party for each election, the most common party listed within the LA grouping of constituencies was taken as the result. The most three common parties—Labour, Conservative, and Plaid Cymru—were studied; they provide an indication of left-, right-, and nationalist-leaning parties, respectively, in terms of their electoral promises and policies.

3. Results

This section presents the trend and statistical analyses that underpins the critical evaluation provided in Section 4. The results are provided as follows:

- Waste produced per person (total, recycled, landfilled, incinerated);
- Trends in waste treatment;

- Separate available kerbside collection methods;
- Political influence;
- Influence of income;
- Impact of policy introductions;
- Other factors.

3.1. Waste Produced per Person

Figure 1 shows the fluctuations in total waste arisings per person per year in Wales. The population increased steadily from just under 3 million in 2006 to 3.15 million in 2019. The waste generated per person seems to show a steady reduction from 2007 to 2011. However, these data were probably miscalculated by the WasteDataFlow system, confirmed by the government department. The values remained relatively steady at ~500 kg per person during 2012–2016. From 2016–2018, there was a decrease in total waste produced per person in Wales at a rate of ~15.6 kg per year.

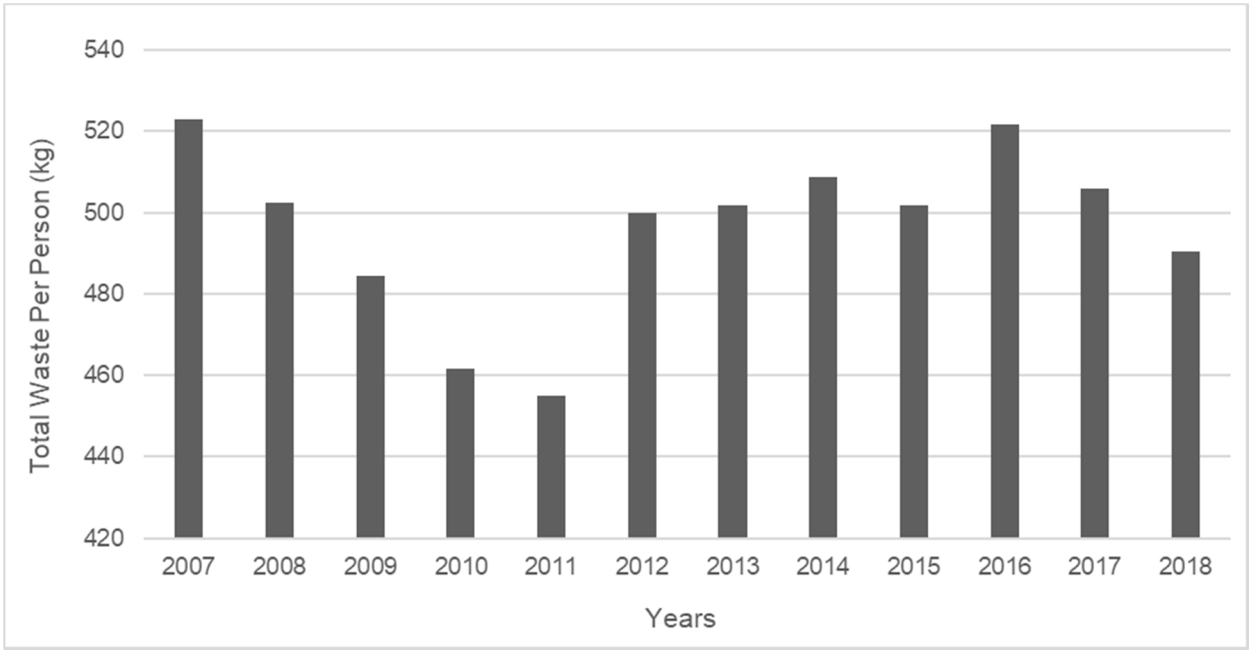

Figure 1. Total yearly municipal waste produced per person (kg); Welsh average. Source: WasteDataFlow and StatsWales.

The trend of total annual recycled waste per person in Wales is displayed in Figure 2. The R^2 value of >0.7 reflects that the stated regression line approximates the real values strongly using averages from over the whole country, despite the obvious seasonal variations (see below). The recycling rate (i.e., the percentage of Welsh LA municipal waste that was reused, recycled, or composted) has increased considerably during the last two decades (from around 5% in the late 1990s). Recycling rates show a seasonal variation due to increases in garden waste sent for composting in the summer. An overall positive trend is observed 2006–2019, rising at an annual rate of ~3.86 kg per person. This value could potentially be used to predict future changes (assuming that prevailing conditions remain the same and recognising that the most influential variation in recent years is the COVID-19 pandemic).

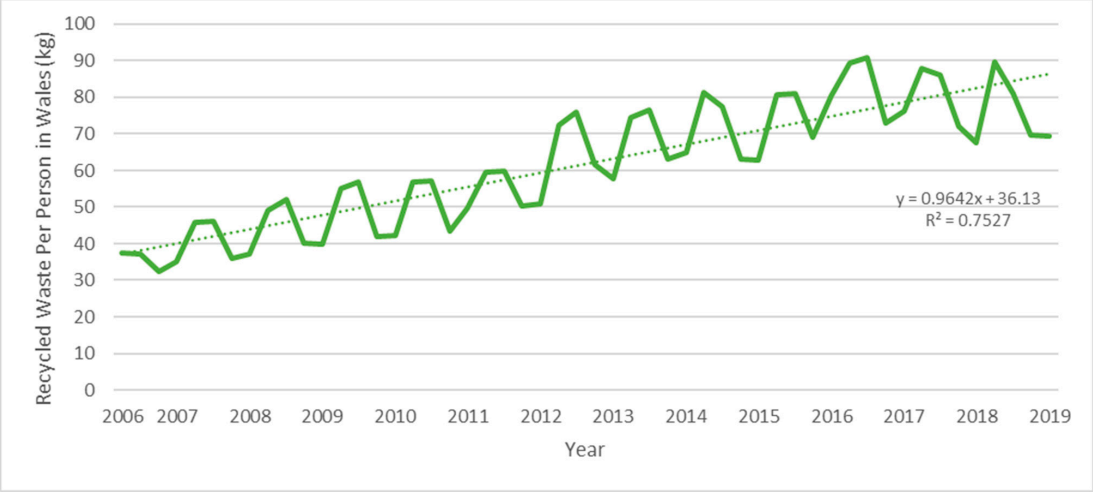

Figure 2. Total recycled waste per person (kg) per quarter; Welsh qverage. Source: WasteDataFlow and StatsWales. Dotted line shows trend line represented also in figure by regression equation and coefficient of determination (R^2).

The total waste sent to landfill annually per person has been gradually decreasing since 2006, as shown in Figure 3. The clear trendline for landfilled waste shows a relatively steep decline over time, with a year-on-year average decrease of ~7.14 kg of waste per person. The R^2 value of >0.95 reflects that the stated regression line approximates the real values very strongly using averages from over the whole country. The annual decrease starts to flatten off from 2016 onwards, and during the pandemic period of 2019–2020, 7.6% of Welsh municipal solid waste was sent to landfill [14].

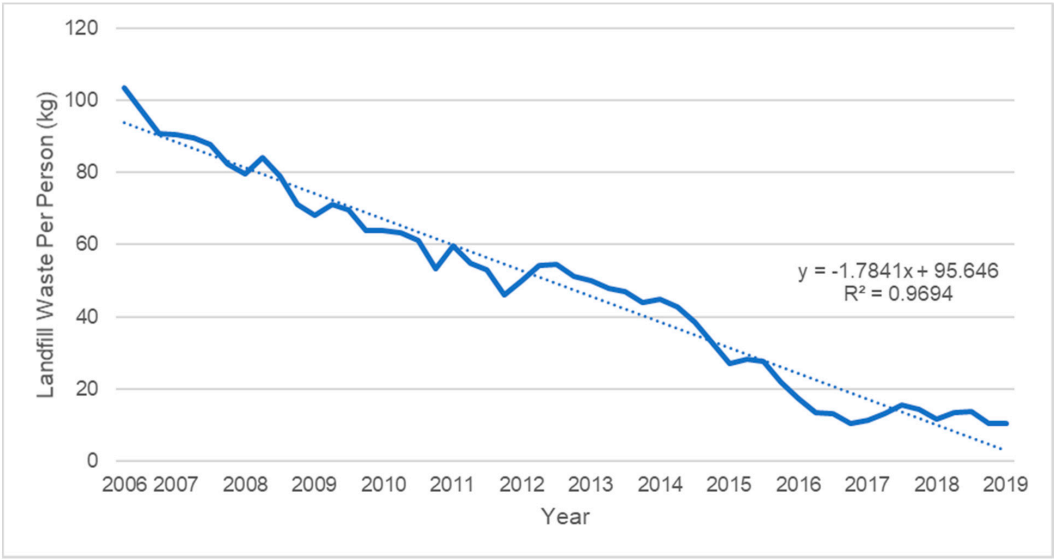

Figure 3. Total landfilled waste per person (kg) per quarter; Welsh average. Source: WasteDataFlow and StatsWales. Dotted line shows trend line represented also in figure by regression equation and coefficient of determination (R^2).

Figure 4 highlights this levelling off in more detail as the annual waste per person to landfill disposal reaches values of <50 kg. The R^2 value of ~0.2 reflects that the stated regression line only weakly approximates the real values. Applying a trendline to the data from 2016 onwards yields a new, lower rate of decrease. This trendline predicts the end of waste sent to landfill to be the year 2030, assuming ongoing steady progress. However,

of course, it is more likely that a very small amount of landfill capacity will be needed for particular wastes.

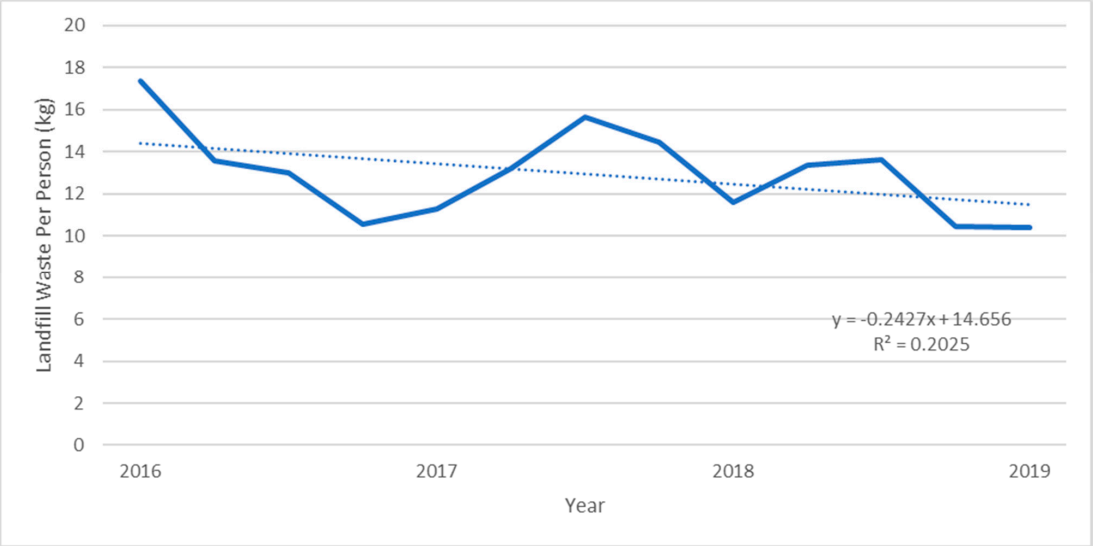

Figure 4. Total landfilled waste per person (kg) per quarter; Welsh Average. Source: WasteDataFlow and StatsWales. Dotted line shows trend line represented also in figure by regression equation and coefficient of determination (R^2).

From 2006, the waste sent for incineration remained very low, below 5 kg per person, per quarter, until mid-2013, when a sharp increase of 9.36 kg occurs between the years 2013 and 2016 due to incineration infrastructure coming online (Figure 5). Since then, this value has fluctuated between 35–40 kg per person per quarter year.

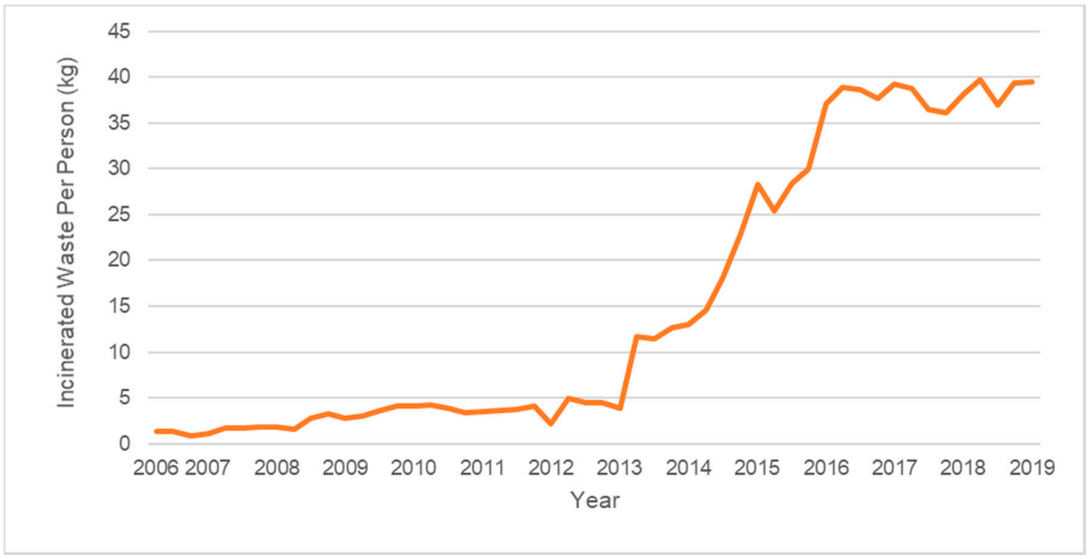

Figure 5. Total incinerated waste per person (kg) per quarter; Welsh average. Source: WasteDataFlow and StatsWales.

3.2. Waste Treatment

Figure 6 shows trends in Welsh waste treatment. The figure shows a steady decrease in landfill usage alongside the ever-increasing use of recycling and a later sudden step-change in incineration. A plateau of ~65% recycling rate can be observed towards the end of the period, with incineration reaching a rate of >25%.

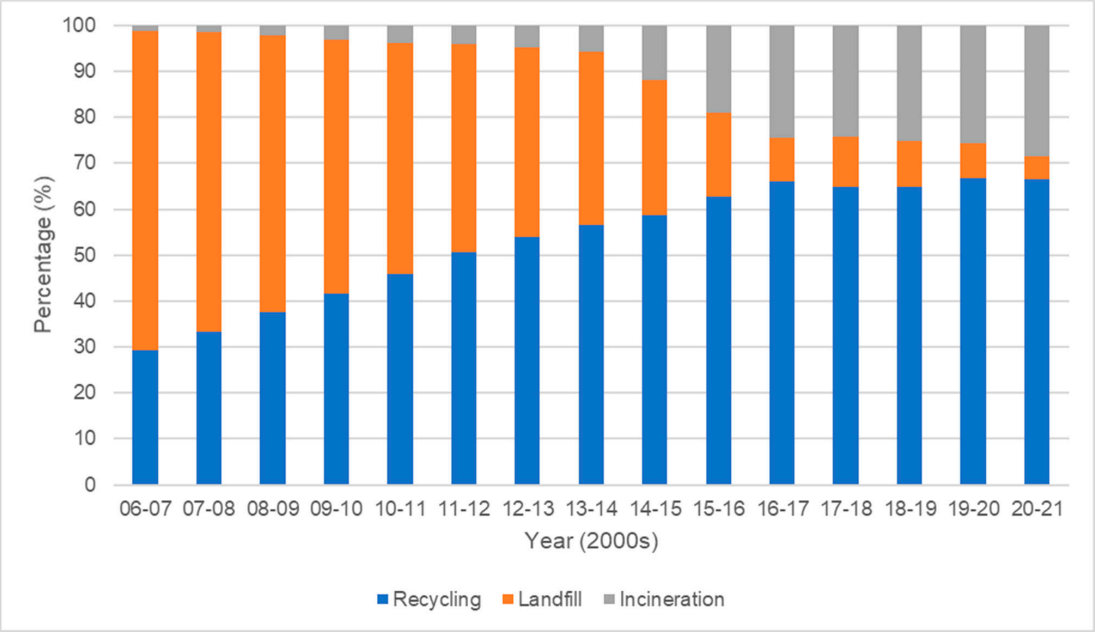

Figure 6. Trends in waste treatment for WalesSource: WasteDataFlow.

3.3. Separate Kerbside Collection Methods

Figure 7 displays the difference in recycling rate by different methods of kerbside waste collection. Regular seasonal fluctuations are again observed (see Section 3.1); these fluctuations impact the R^2 values, which reflect that the stated regression lines approximate the real values moderately in both cases, although more strongly with nine separate collections. LAs that have a lower number of separate collections show consistently higher recycling rates than those with a higher number, with a sudden change during the COVID-19 pandemic. It is worth noting that over 2012–2019, LAs with higher number of separate collections show a 1.64% yearly increase in recycling rate compared to a 1.24% rate of increase from those with four to five collections.

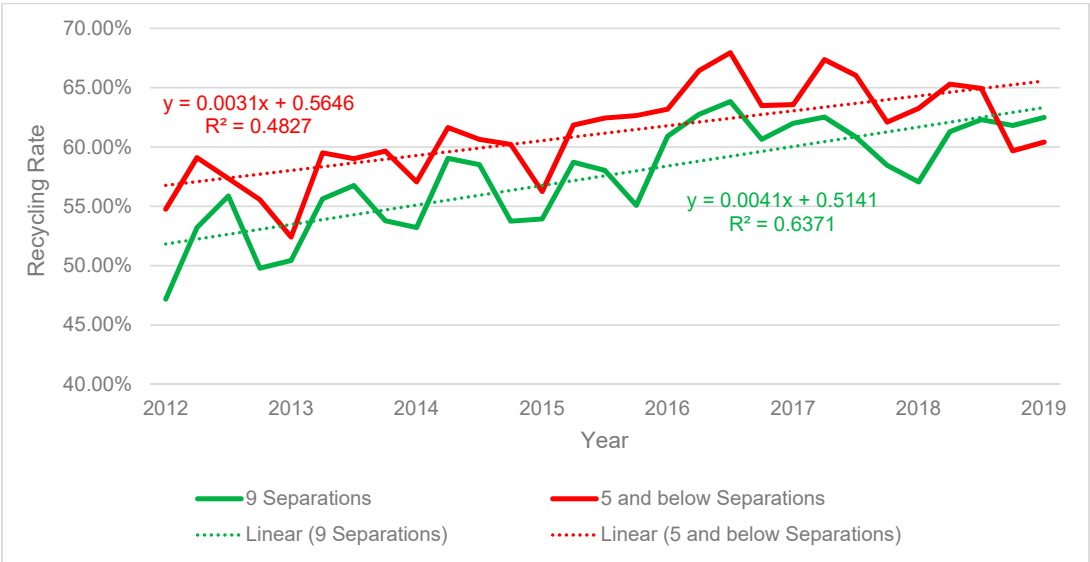

Figure 7. Total recycled waste of local authorities (LAs) with the most and least separated collection methods of kerbside waste per quarter. Source: WasteDataFlow and each LA website. Dotted lines (by colour) show trend lines represented also in figure by regression equations and coefficients of determination (R^2).

The range of approaches to collection taken in Wales is evident from the variation in collection methods for each Welsh local authority shown in Appendix A. Every LA has separate collections for food and green waste, as demanded by law, and all but five have separate collections for glass, which is not often mixed with other materials.

3.4. Political Influence

There are no significant differences between the datasets seen in Figure 8, which show recycling rates by LA political party winners, demonstrated by the almost identical regression equations and strong R^2 values, all >0.85. This highlights that the overarching and consistent country-wide approach to recycling in Wales trumps any minor changes applied locally. All sets show the usual seasonal fluctuations and follow a steady increase in recycling rate from 24–30% in 2006 to all achieving a rate of ~62% in early 2019. There are noteworthy spikes during mid-2009 and again in mid-2014. From 2016 onwards, all averages converge and show a plateau at 60–65%. Labour-held constituencies, which tend to have the most deprived communities, are often slightly the worst performing in recycling rates.

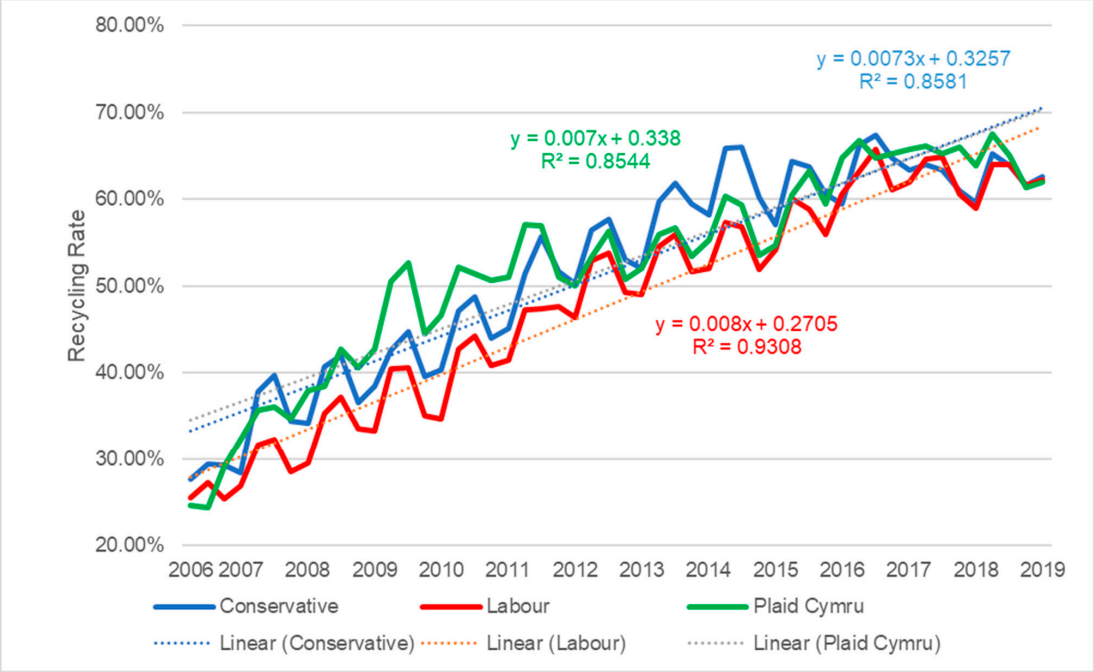

Figure 8. Recycling rate for local authorities (LAs) categorised by majority of election wins per political party. Source: WasteDataFlow.

To test this theory, Labour and non-Labour LAs are shown by recycling rate in Figure 9. The figure clearly shows that LAs categorised as Labour held from 2007–2016 consistently show marginally lower recycling rates in comparison to non-Labour LAs. However, from 2016 onwards, the values by party are indistinguishable.

3.5. Influence of Income

Figure 10 illustrates the average total annual waste produced per person for the four highest and four lowest income LAs in Wales. The seasonal variations in the highest and lowest earning LAs are much more marked than the country-wide variations shown in Figure 2; this is clearly reflected in the very weak R^2 values for both categories. This is mainly due to the highest earning households having much more outside space than the lowest earning households, with consequences for garden waste (and related) arisings. It is thus very clear that deprivation, as indicated by differences in income, influences total waste arisings. By examining the lowest earners exclusively, we can see that there is a

small steady increase (0.06 kg yearly) in waste arisings throughout 2012 to 2019, except for 2016, when some lower income LAs (e.g., Merthyr Tydfil) changed from a co-mingled collection method to several separate boxes/bags, causing temporarily disruption. This spike brought the average waste arisings for the lowest earning local authorities to match that of the peak of highest earning authorities for the only time. The highest earning LAs show a steady decrease in waste production of 1.32 kg yearly. The trendlines converge by 2019.

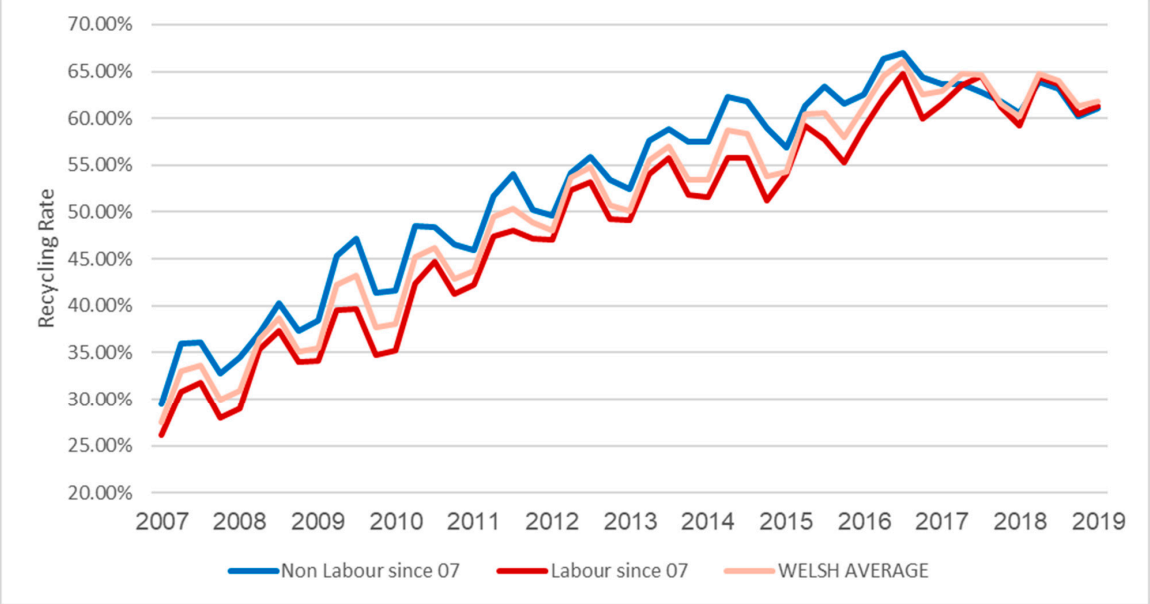

Figure 9. Recycling rate of local authorities (LAs) that have/have not been held by the Labour Party since 2007. Source: WasteDataFlow.

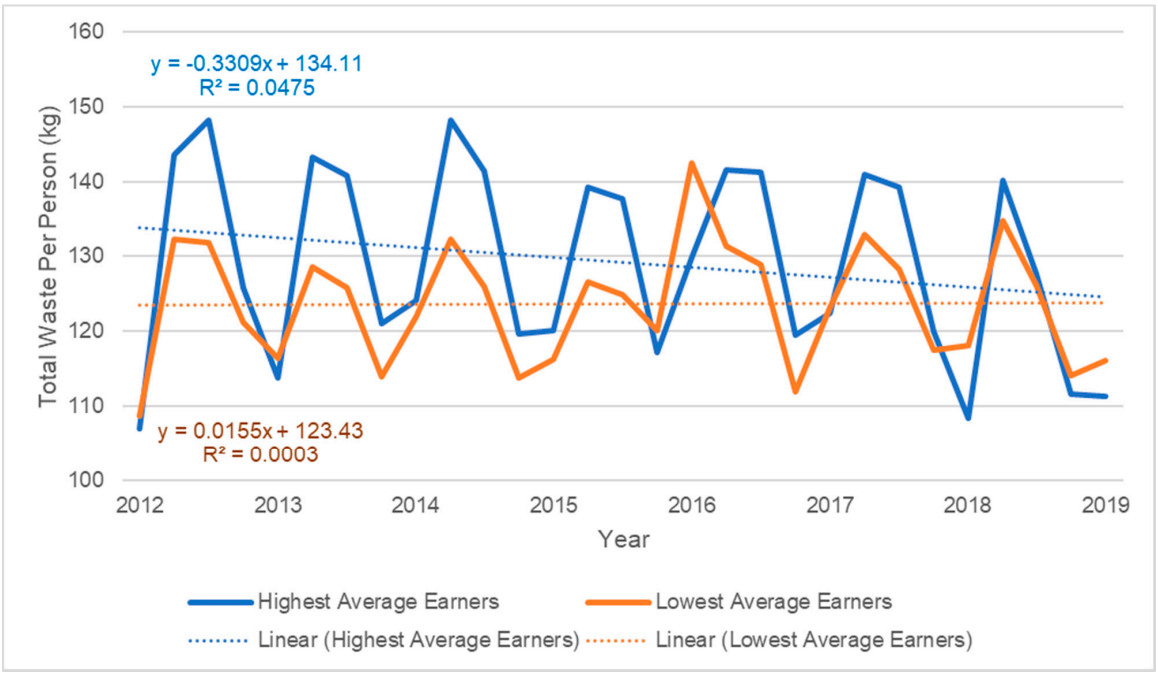

Figure 10. Total waste per person for the averaged highest and lowest earning local authorities in Wales. Source: WasteDataFlow and StatsWales. Dotted lines shows trend lines (by colour) represented also in figure by regression equations and coefficients of determination (R^2).

3.6. Impacts of Policy Introductions

The reasoning behind publishing new policies and targets is to achieve an improvement in performance of the waste management system. Thus, when the WAG release new strategy changes in response to recycling rate, and turn words into deeds by amending infrastructure and service provision inline with strategy, a subsequent improvement is expected. By examining, solely the impact of the second to most recent publication regarding recycling targets [15] increases in recycling rate were clearly observed (see Figure 11). Regular incremental improvements were consistent until 2016–2017. The biggest step change occurred in 2015 when collection methods were changed by many LAs to capture more recyclables separately. The diminishing rate of increase from 2016–2017 is consistent with the phased introduction of incineration infrastructure, as noted previously and critically discussed in Section 4.

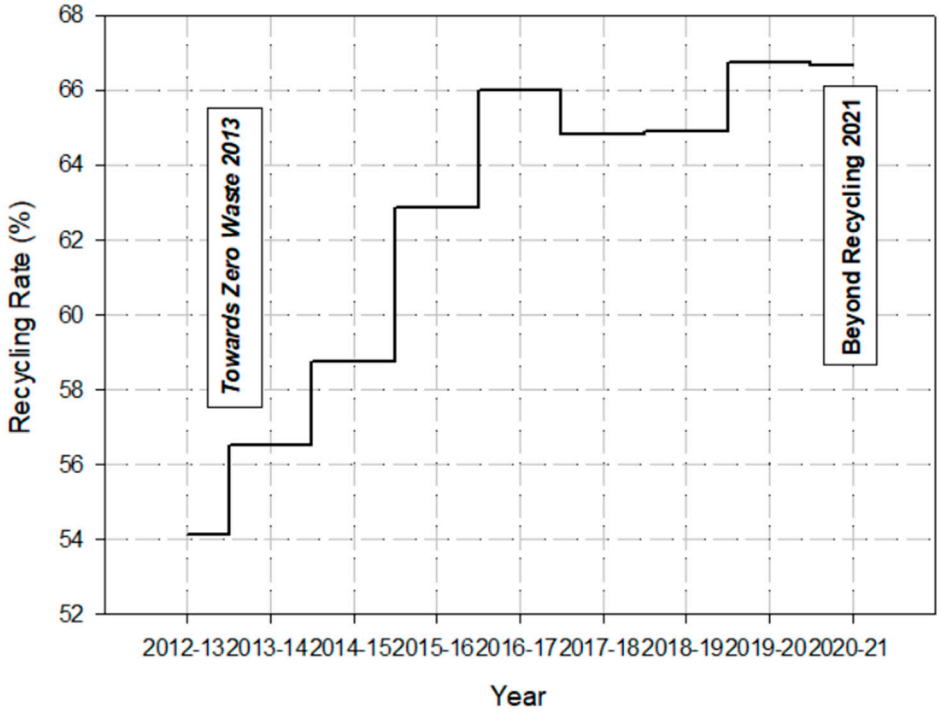

Figure 11. The impact of recent policy changes on recycling rate—Source: WasteDataFlow and Government Publications.

3.7. Other Factors

Figures A2–A7 in Appendix B show other data trends investigated. Waste data associated with the location of a local authority in Wales, age profiles, and attractiveness to tourism were studied. No notable trends, observations, or relationships relating to location, age profile, or numbers of tourists were observed.

4. Discussion

Historical trends in landfill, recycling, and incineration in Wales from 2006 to 2020 have been reviewed. The overarching results provide clear evidence that demonstrate what can be achieved when a government politically prioritises and encourages participation in household recycling by turning words into deeds. There is a large variation in local authority performance across Wales, something previously reported in England [8].

The fluctuations in total waste produced per person are due to several factors, including increased urbanisation, economic development (until more recent years), changes to shopping habits, and improvements in standard of living [16,17]. The expected increase in waste arisings due to these factors has been combatted by the WAG's initiatives to encourage the reuse of items and recycling as well as a focus on eliminating single use

plastics [15]. It has been supported by dominant chain superstores implementing initiatives to reduce packing on their items; these companies can have a big impact on an area's waste statistics due to their size and popularity [18]. Major UK supermarkets set initiatives to be more sustainable in terms of packaging, food, and product waste (e.g., Tesco, Asda, and Sainsbury's). These two changes in total waste production are likely to cancel out, as seen from 2012 onwards.

Between 2016 and 2018, annual waste per person in Wales decreased by 15.62 kg, a stark contrast to the prediction made by the World Bank, which expected global waste to grow by 70% by 2050 without taken [19]. This highlights the importance of the proactive approach taken by the WAG to support its strategy towards a circular economy for Wales [20].

Seasonal fluctuations are evident from Figure 2, mainly caused by garden waste. During the summer months, those with grass-dominated gardens will have more of this type of waste to be composted than in winter months. This is due to the summer conditions allowing for a faster rate of growth than normally observed. As this waste is considered in the recycling total, large fluctuations are seen when reading data by yearly quarter. Regardless of these seasonal changes in the data, the overall recycled waste has continued to increase throughout this period.

By following the observed increase of 3.86 kg yearly, and assuming a constant waste production of 490 kg, consistent with the most recent readings in 2018, and using the trendline prediction of current waste production of 86 kg, it would take until the year of 2123 for 100% of waste production to be recycled, assuming that this became technically possible. The WAG's action plans have focused on setting statutory targets, reduction in cross-contamination, improving public awareness and recycling facilities; and these have clearly contributed to an improvement of the Welsh recycling rate [19]. The WAG has set many statutory targets regarding recycling, surpassing the EU's targets and surpassing the targets of their UK counterparts [21]. The most recent target set, in the Beyond Recycling publication [22] is 64%. Local authorities that do not attain this objective within the timeframe, will be fined £200 per tonne [23]. This will also apply to the 70% target set to be achieved by 2025. Thus, LAs are incentivised to achieve such goals to avoid being fined.

Many Welsh LAs have implemented a scheme that increases the number of varying separations for kerbside recycling, with 59% of the 22 local authorities currently running seven or more separate collections. This initiative was expected to reduce cross-contamination and to produce an acceptable quality of recyclate [24]. A range of approaches have been taken by LAs across Wales. Some, such as Caerphilly, decided not to deviate from the comingled collection method for the whole time analysed, whereas others, such as Conwy currently have nine separate kerbside collection options (see below). Historically, increasing the range of material collected and simplifying collection systems has been shown to increase recycling and decrease the residual waste stream [8], although more recent data show that co-mingled collections lead to higher contamination of recyclates that are then not able to be sold for recycling [25].

Public knowledge about recycling has been stimulated by the organised campaign of "Recycle Week", which started in 2003 and plays a big in role in highlighting the importance of recycling actions households can take and encourages more to get involved. Schools throughout Wales are stimulated to get involved with the eco-schools campaign, where a group of young learners form a committee to tackle environmental issues, which includes waste production, and subsequently aim to raise a "green flag". Many campaigns and public outreach programmes have been targeted at the Welsh public to increase awareness and introduce new ideas, as heard on national radio stations [26]. Many studies have shown that householders who understand the need for, and benefits of, recycling participate more [27,28]. Education and promotion of recycling is necessary alongside improved infrastructure and services to effect behavioural change and enhance participation [29–32].

Recycling facilities across Wales have been targeted for improvement for several years, specifically recycling centres for non-kerbside waste were targeted by WAG to allow an increase in recycling rates following the inclusion of bulkier, non-feasible material collections

such as construction waste, vehicle deposits, and waste from house renovations [6]. Many sites now handle over 20 waste streams, with some also housing small shops, taking in items that were deemed as not ready for end-of-life treatment, and sold to be reused [19]. This has allowed a larger percentage of waste to be disposed of responsibility and potentially sustainably, increasing the total waste recycled.

In recent years, the extensive damage landfilling waste can induce on our planet has been highlighted. Its effects include the production of greenhouse gases [33], soil contamination [34], and human health [35]. Danthurebandara et al. [36] reported that landfills contributed 20% to the total global anthropogenic methane production. Wales was historically heavily reliant on landfill for waste management and so moving away from this pathway quickly posed a significant problem for the WAG. Figure 3 shows a downward trend the use of landfill for Welsh waste, with a plateau from 2016 onwards. This is likely due to the challenges faced in achieving zero waste to landfill, as subsidiary products from other waste management techniques, such as ash and other hazardous waste cannot be recycled. Whilst the WAG's approach has successfully and quickly reduced waste disposed via landfill, further reductions will be more challenging. These data illustrate the Pareto Principle, which suggests that 80% of outcomes come from 20% of causes [37].

Figure 5 shows total incinerated waste per person in Wales from 2006 to 2019, with a sharp increase from 2013–2016 as facilities came onstream, and a subsequent plateau. The sharp increase in incineration matches the opening of the largest energy recovery facility (ERF) in Wales—the Viridor Cardiff ERF opened in mid-2014 [38]. Other incineration plants were used before (and after) the opening of the Cardiff Viridor ERF. Incineration with energy recovery is preferable to landfill since the immediate emissions related with incineration are less environmentally damaging in the long term compared to methane production associated with landfill [39–41].

Figure 6 shows that recycling plateaus at the same time as incineration comes on stream; Farmer et al. [8] demonstrated that once a LA's waste destinations become reliant on incineration (so-called "feeding the beast"), incentives to enhance other means for waste management are diminished. This occurs for several reasons e.g.,

- Many materials are incorrectly placed in the residual waste stream and hence a substantial proportion of what is currently incinerated could have been recycled or composted [42];
- Diverting material to incineration does not require public behaviour change [8];
- The majority of UK incinerators have no facilities to remove misplaced material prior to incineration, and so all of the recyclable/compostable material delivered ends up being burned;
- The use of incineration usually involves long-term contracts (20+ years) containing clauses that penalise local authorities for not sending enough waste to incinerators, undermining the desire/incentive to transition to waste destinations more desirable under the principles of the waste hierarchy (reduce, reuse, recycle, and compost) [8].

There are substantial data from the UK that show a strong association between higher rates of incineration and lower recycling rates [43,44]. In Wales, a strong case was made for incinerating plastics rather them letting them sit in landfill, as reflected in the WAG strategy changes at the time. Plastics have a high calorific value, meaning the incineration would yield more energy recovery than other materials. Plastics also have the second longest breakdown times of any materials sent to landfill, approximately 200–500 years, and is estimated that discarding plastics to landfill accounts for >15% of all methane production [45]. Thus, a decision was made to redirect plastics to the energy recovery rather than landfill if the option of recycling is not available.

Figure 7 displays the total recycled waste of LAs with the most and least separated collection methods of kerbside waste per quarter. The regular seasonal fluctuations due to the increase in grass/garden waste in summer can be observed throughout. One of the three LAs with the highest number of collection methods, Merthyr Tydfil, experienced an unusual surge in recycled waste per person. This is because in early 2015 the LA initiated a

change from co-mingled collection to several separate boxes/bags. Under the same change of scheme, in January 2015, the authority also changed the size of the wheeled residual waste bin, reducing it from 240 l to a streamlined 140 l version [46,47].

This graph implies that the Welsh public values convenience highly when it comes to recycling. While both datasets show an overall increase in recycling rate, a yearly average increase of 1.64% was calculated for those local authorities with nine separate collections, whereas an increase of 1.24% is seen for those with the lowest number of collection methods. However, it must be noted that those LAs considered for having the highest number of separate collections were not in this category for the whole period as changes were made at different times within the timeframe provided. The categorisation of these LAs was determined by using current number of separate kerbside collections. Whilst LAs with a higher number of collections experience a slightly faster rate of increase over the period, both datasets show times of great progression, stagnation, and, at some times, regression. Figure 7 shows that the recycled waste from authorities with the lower number of collections fell beneath the opposing dataset in 2019; this is primarily due to a relatively weak performance from one authority (Carmarthenshire, which operates co-mingled collection) in recent years, with it ranking 22nd out of the 22 local authorities for the 2018-19 review [48].

A clear convergence is visible in more recent years, highlighted by the trend lines. This partially coincides with the introduction of infrastructure for incineration. It is also highly likely that the Welsh public are broadly content with the way in which they have been asked to recycle their waste, and that this has become habitualised. This suggests that the difference in number of collections is no longer a significant determinant in recycling rate, although contamination of co-mingled material remains a problem [25].

Figure 8 shows the recycling rates of LAs categorised by the three most dominant political parties in Wales. A clear difference through the period is not observed. Labour, who historically hold the most constituencies throughout the country, are often the lowest performers in terms of recycling rates, with LAs held by other parties performing in a very similar fashion (Figure 9). This has probably been caused by several factors. The South Wales Valleys are a group of industrialised peri-urban valleys in South Wales that have suffered profoundly from the decline of heavy industry [49]. All Valley classified LAs were held by Labour in this analysis. The so-called "Valleys area" generally underperforms across a range of economic indicators, with 55% of the valley population living in areas where more than 175 per 1000 of the working population claim benefits, compared to the Welsh average of 33%. There are many indicators for the valleys to be in a larger state of deprivation in comparison to the country [50]. It is reasonably well-established that recycling rates are lower in poorer areas of the UK [51].

In addition, the other LAs that are included in the Labour classification for Figure 8 are mostly those who have a larger population density. Those who reside in these areas such as Cardiff and Swansea, including large populations of students, are more likely to live in flats or houses of multiple occupancy, where the percentage of HMOs of the Welsh total are 35.8% and 10.2%, using the estimated values for the most current year available [14]. The inconvenience of properly separating waste within a small liveable area and then carrying waste to a distanced sorting room, which could be several floors away, is a barrier to recycling [52]. Even those who are committed to recycling just need to be housed with an individual who is non-committal to destabilise a recycling regime through contamination [53]. We can therefore see why links have been made between deprivation, housing type and life stage against participation in recycling [54].

Figure 10 shows the total waste per person for the averaged highest and lowest earning local authorities in Wales. Given that those who have higher incomes are more likely to reside in a house with reasonable outside space, and low-income households tend to inhabit areas of high density, such as flats or houses of multiple occupancy, it is unsurprising that seasonal variations due to garden waste are very marked. Higher earners, with more access to outside space per person, are going to dispose of considerably more

organic waste during the summertime. However, the trendlines for both datasets start to converge towards the end of the period. The total waste per person from the lowest earning LAs remains relatively consistent, indicating no change in performance, whilst the total waste per person from the highest earning LAs shows a steady decrease. The reasons for this are unclear, although it is possible that households in the highest earning LAs have started to change (reduce) their consumption behaviour as shifting values, expectations and motivations around culture, community and environment start to have an impact on consumption habits and patterns.

Figure 11 shows the impact of policy changes over time. The step changes, year by year, are steep in the years following the significant initiatives introduced in 2013. The observed improvements continue up to the years of 2016–2017, when new incineration infrastructure comes fully online. The gradual increases in recycling rate following the publication of new policy changes, made in the *Towards Zero Waste* [15], highlight the time lag between the introduction of this type of policy and creation of infrastructure/services, habitualisation of intended behaviours and resulting outcomes. The WAG's newest strategy, *Beyond Recycling 2021* [22], intends to enable an increase in recycling rate by 2025, the target deadline for the intended 70% recycling rate. The strategy ultimately aims to make Wales a world leader in reuse, repair, and manufacturing from recyclable materials—by 2050 it wants to reuse, recycle, or repair everything. It is based on six themes: driving innovation in materials use; upscaling prevention and reuse; building on Wales's recycling record; investing in infrastructure; enabling community and business action; and aligning Government levers.

5. Conclusions

Over the last 15 years, Wales has become a world leader in household waste recycling. A review of historical trends in waste management in Wales from 2006 to 2020 shows that the positive and proactive approach taken by the WAG has achieved impressive results that contrast starkly with the recycling performance of other UK countries; they have successfully turned words into deeds. England's *laissez-faire* approach realised a paltry 4% increase in recycling rate in the decade prior to 2020, with Scotland also failing to meet its target and Northern Ireland only just meeting it. The WAG politically prioritised and encouraged participation in household recycling. Its action plans focused on setting statutory targets, reduction in cross-contamination, improving public awareness and recycling facilities, and provision of infrastructure, particularly incineration capacity. In particular, the difference between Wales's progressive, ambitious, joined-up, evidence-and consensus-based, and partnership-driven approach to resource management and the vision-free, leadership-free, rather siloed processes that have occurred in England is like the difference between chalk and cheese.

In Wales, household waste disposed annually per person via landfill has very significantly decreased from ~410 kg to <50 kg. Over the same period, the amount of household waste recycled annually per person has increased from to ~150 kg to ~310 kg, with a recent increase in incineration with energy recovery to ~135 kg as infrastructure has come online. Recycling rates show a seasonal variation due to increases in garden waste sent for composting in the summer. There are variations in local authority performance across Wales, mainly caused by variations in the number of separate collections; LAs that have a lower number of separate collections show consistently higher recycling rates than those with a higher number, with a sudden change during the COVID-19 pandemic. However, co-mingled collections tend to lead to higher contamination of recyclates that are then not able to be sold for recycling. Deprivation, as indicated by differences in income, also influences total waste arisings and recycling rates.

A plateau of ~65% recycling rate can be observed towards the end of the period, with incineration reaching a rate of >25%. The recycling rate plateaus at exactly the same time as incineration comes on stream, highlighting the phenomenon known as "feeding the beast" and emphasising that improvements to recycling rates can become more difficult

when convenient alternative long-term infrastructure is available, even if it is lower in the waste hierarchy.

Whilst the WAG's approach has successfully and quickly reduced waste disposed via landfill, further reductions and improvements to recycling will be more challenging. The WAG has responded to the challenge by publishing its strategy to make Wales a zero-waste nation by 2050 by developing a full circular economy [22]. The strategy has been designed to make resource efficiency part of Welsh culture and to help the country maximise its economic potential. The WAG's track record shows that it tends to deliver on its waste-related plans and suggests it has the best chance of any of the UK's four countries of achieving its aims.

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Appendix A

Column1	General	General Recycling	Food	Garden	Glass	AHP (Incontinence)	Paper	Plastic	Textiles	Electronic	Metal Packaging	Cardboard	Aerosols	Batteries	TOTAL #:	Weeks between Black Bag Collection
Carmarthenshire County C	●	X	●	●	○	X	●	●	○	○	●	●	●	○	4	2
Denbighshire County Coun	●	X	●	●	●	X	●	●	X	○	●	●	○	○	4	3
Caerphilly CBC	●	X	●	●	●	●	●	●	X	X	●	●	●	X	5	2
Cardiff County Council	●	X	●	●	●	●	●	●	○	○	●	●	●	○	6	2
City and County of Swans	●	X	●	●	●	○	●	●	○	○	●	●	●	○	6	2
Rhondda Cynon Taff CBC	●	●	●	●	●	●	●	●	○	○	●	●	●	○	6	2
Torfaen CBC	●	●	●	●	●	●	●	●	●	○	●	●	●	○	6	2
Powys County Council	●	X	●	●	●	○	●	●	○	○	●	●	●	○	6	3
Ceredigion County Council	●	X	●	●	●	●	●	●	○	○	●	●	●	○	6	2,3
Monmouthshire CC	●	X	●	●	●	●	●	●	○	○	●	●	●	○	7	2
Newport City Council	●	X	●	●	●	●	●	●	●	●	●	●	●	○	7	2
Wrexham CBC	●	X	●	●	●	X	●	●	●	○	●	●	●	○	7	2
Bridgend CBC	●	X	●	●	●	●	●	●	○	○	●	●	●	○	8	2
Flintshire County Council	●	X	●	●	●	●	●	●	○	○	●	●	●	○	8	2
Neath Port Talbot CBC	●	X	●	●	●	X	●	●	○	○	●	●	●	●	8	2
Vale of Glamorgan Council	●	X	●	●	●	●	●	●	○	○	●	●	●	○	8	2
Gwynedd Council	●	●	●	●	●	●	●	●	○	○	●	●	●	○	8	3
Isle of Anglesey CC	●	X	●	●	●	●	●	●	●	●	●	●	●	●	8	3
Blaenau Gwent CBC	●	X	●	●	●	●	●	●	●	●	●	●	●	●	9	3
Merthyr Tydfil CBC	●	X	●	●	●	X	●	●	●	●	●	●	●	●	9	3
Pembrokeshire County Cou	●	X	●	●	●	●	●	●	○	○	●	●	●	●	9	3
Conwy CBC	●	X	●	●	●	X	●	●	●	●	●	●	●	●	9	4 since 2018

Figure A1. Variation in Collection Methods for Each Welsh Local Authority (LA). Source: Each LA Website.

Each coloured spot relates to a new separate collection, if two categories have the same colour spot they are collected together. Black circles indicate that items can be recycled separately within the LA but not at the kerbside.

Appendix B

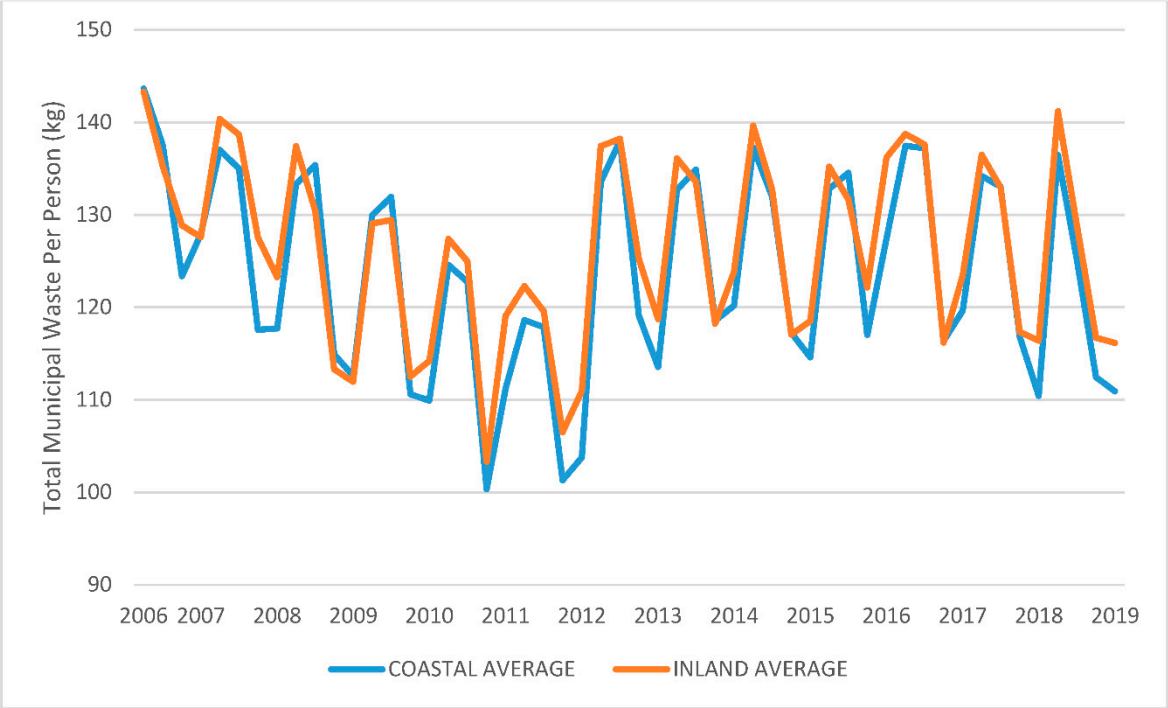

Figure A2. Total municipal waste per person for coastal and rural local authorities in Wales per quarter. Source WasteDataFlow.

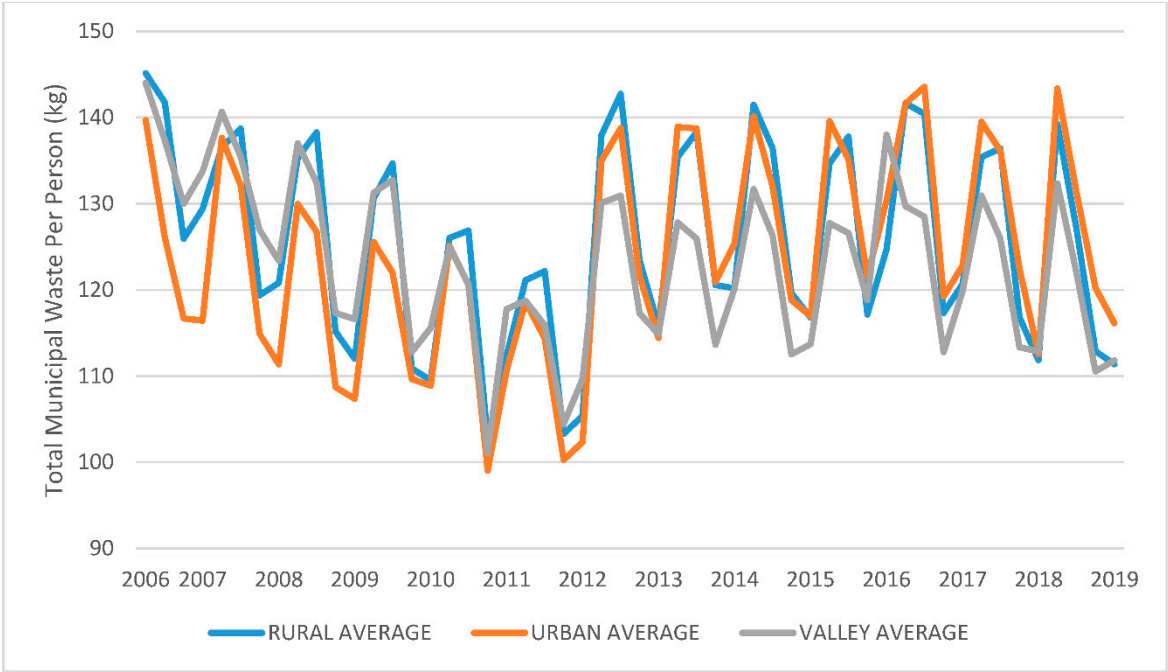

Figure A3. Total municipal waste per person for rural/urban/valley local authorities in Wales per quarter. Source WasteDataFlow.

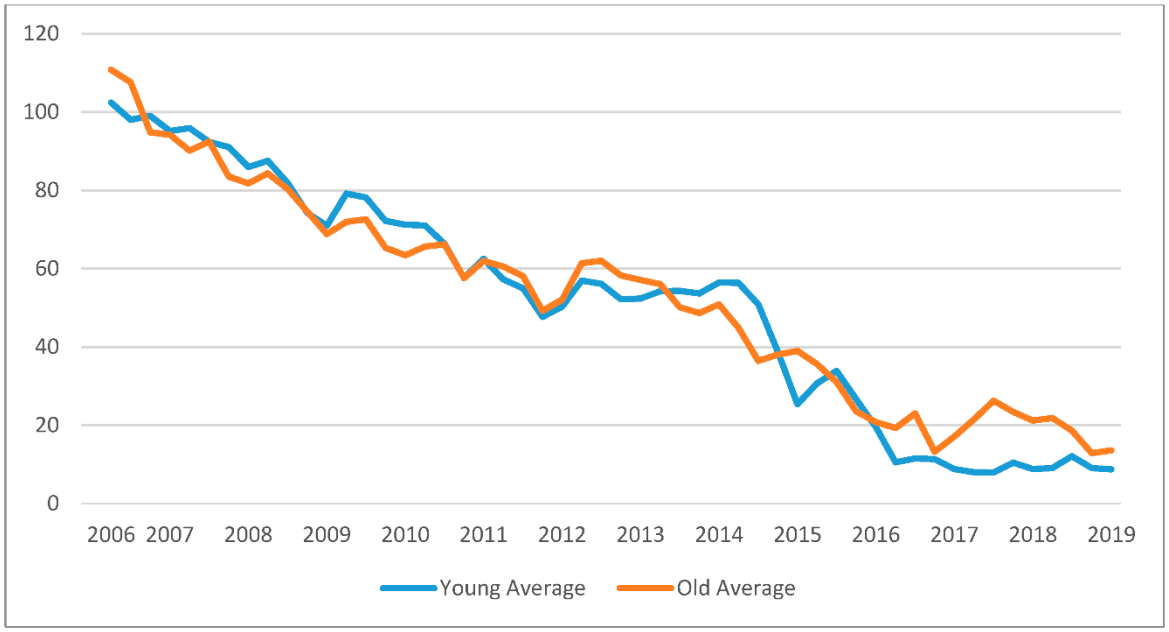

Figure A4. Total landfill waste (kg) per person by average age in the youngest and oldest local authorities in Wales – quarterly. Source: WasteDataFlow.

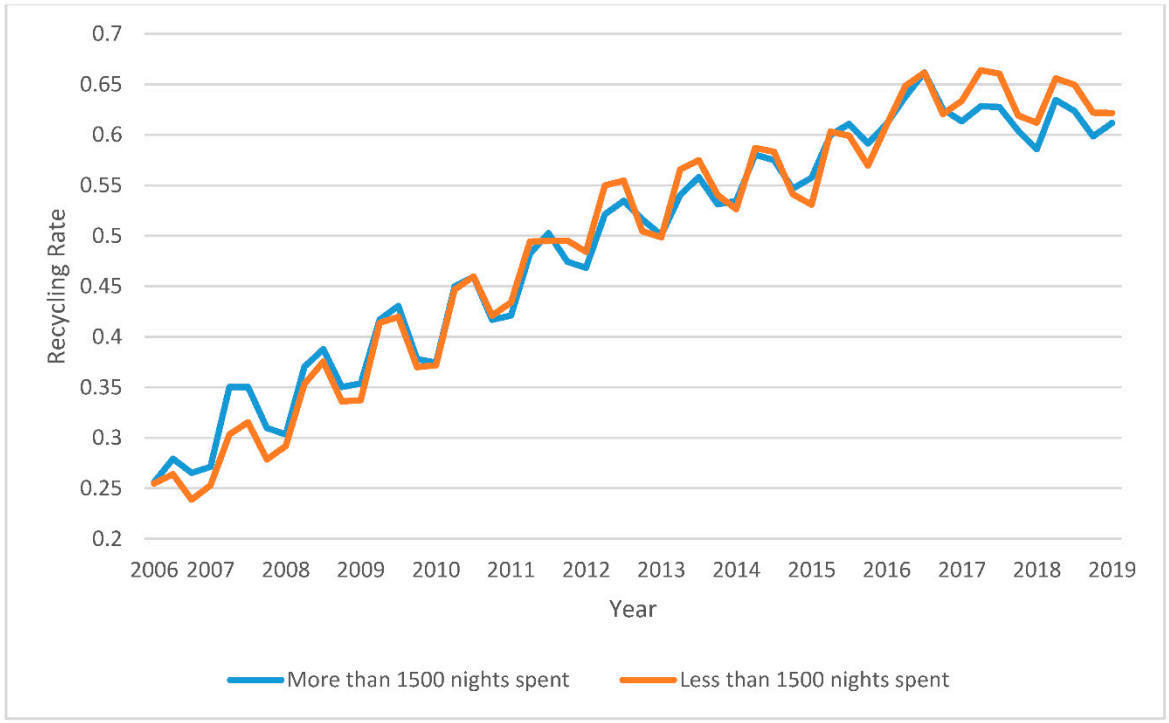

Figure A5. Average recycling rate for local authorities with more/less than 1500 nights spent in by international travellers per year. Source: WasteDataFlow and the Tourism Profile.

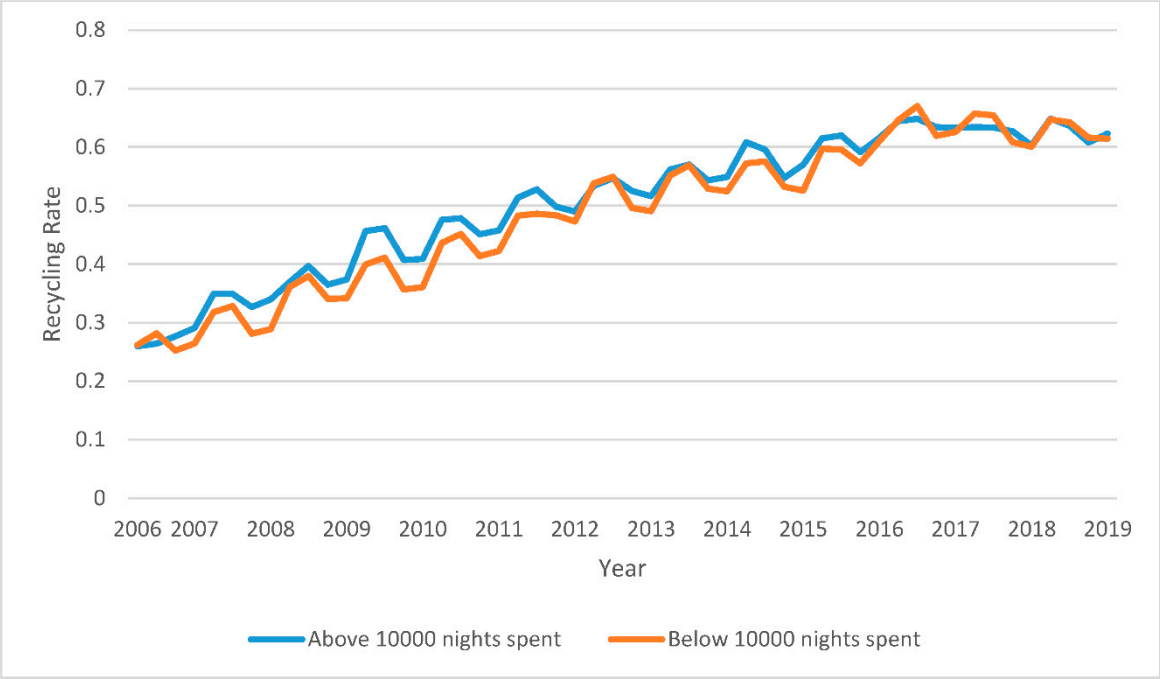

Figure A6. Average recycling rate for local authorities with more/less than 10,000 nights spent in by domestic travellers per year. Source: WasteDataFlow and the Tourism Profile.

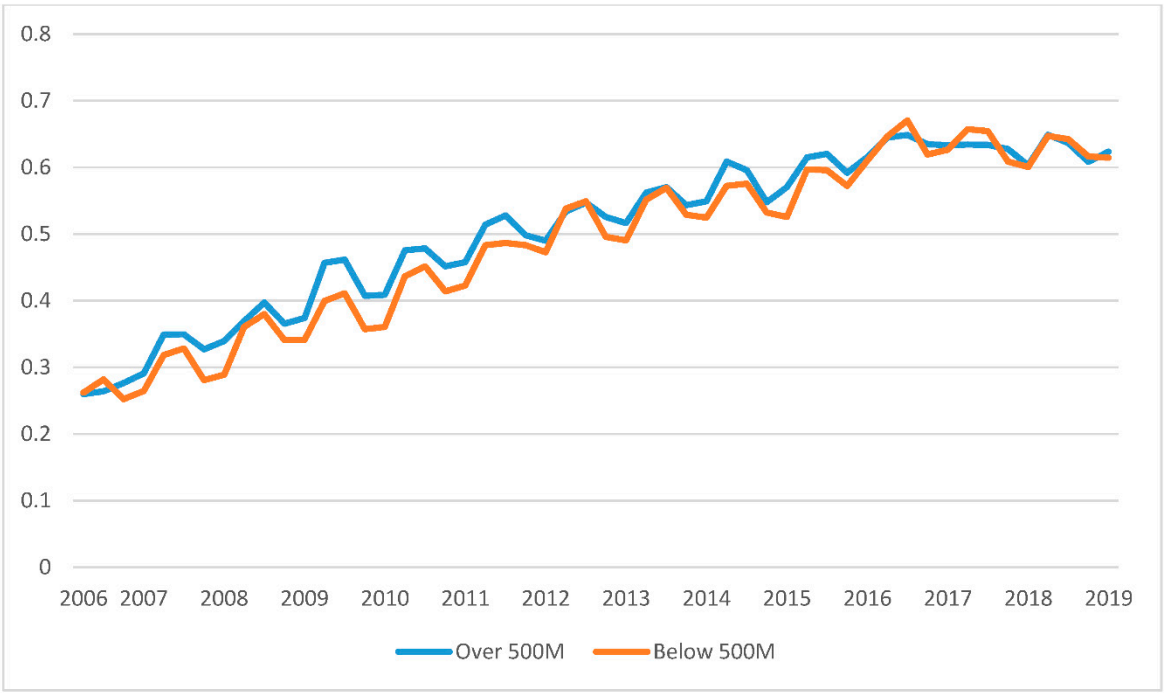

Figure A7. Average recycling rate for local authorities that have had more/less than 500 million pounds spent in by all overnight travellers from 2011 to 2019. Source: WasteDataFlow and the Tourism Profile.

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