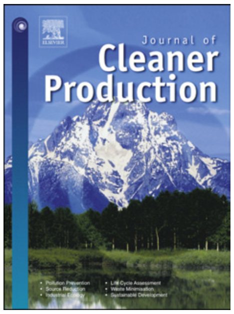

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Material Flow Accounting in an Irish City-Region 1992-2002

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ABSTRACT

This paper aims to measure raw material inputs and waste flows in an Irish city-region in order to analyse (i) whether there was absolute dematerialisation in the particular case-study over the period 1992-2002 and (ii) whether material consumption and waste generation were decoupled from economic growth and increases in disposable income over the same period. It was found that the selected material flow indicators showed no evidence of absolute dematerialisation over the given study period, although more recent evidence at the national level suggests that a decline in construction activity and extraction of non-metallic minerals has resulted in an absolute reduction in material consumption and it is likely that this will be mirrored at the system boundary level.

It was found that Domestic Material Consumption (DMC) per capita and Direct Material Input (DMI) per capita increased at a faster rate than Domestic Processed Output (DPO) per capita and Direct Material Output (DMO) per capita between 1992 and 2002, which indicates relative decoupling of consumption from waste generation. In addition, it was found that there was relative decoupling of consumption and waste generation from disposable income growth over the study period. Finally, it was found that average DMC and DMI figures for the selected case-study were lower than the national averages but broadly similar to results for other city-regions in the European Union (EU). On a methodological note, it was concluded that material flow accounting (MFA) for city-regions in Ireland is constrained due to a lack of disaggregated data for material flows, with the exception of local waste data, and it is recommended that bottom-up analysis should be used to complement disaggregated top-down data.

Key Words: Material Flow Accounting, Dematerialisation, Decoupling

1. Introduction

The objective of this paper is to analyse material flows, energy consumption, solid waste generation and total emissions, including greenhouse gases (GHG) emissions and other air pollutants, in an Irish city-region in order to determine the scale of material consumption and waste output. This analysis is undertaken using a static model, which measures annual material and waste flows in a time-series and allows for trends to be inferred over a particular timeframe. Section 1 introduces the concept of material flow accounting (MFA) and its applications; defines dematerialisation and decoupling and evaluates empirical work on urban metabolism. Section 2 outlines the methodology and data sources used in this paper. Section 3 presents the results of the MFA analysis, using a range of indicators. Section 4 evaluates the MFA results and offers final conclusions.

1.1. Material Flow Accounting (MFA)

MFA allows for a holistic view of resource management with the objective of moving the emphasis away from end-of-pipe solutions towards the prevention of waste and the minimisation of material and resource use at source and along the process chain. This approach involves looking at material inputs and waste outputs as well as inefficiencies in the supply chain in terms of the processing and transformation of materials. It also allows for opportunities for waste prevention, minimisation and recycling to be identified.

In particular, MFA aims to quantify or account for the flow of raw materials, resources and/or intermediate or finished products, in physical units, from the point of extraction, through the processing and manufacturing stages, to their ultimate disposal. MFA is generally undertaken for a defined geographical area or industry sector over a set period of time in order to identify points in the lifecycle where resource use is most inefficient. It is also used to track the types and quantities of wastes produced and allows one to document flows of material and energy both between natural and socio-economic systems and within socio-economic systems

(Linstead and Ekins, 2001; O'Leary and Cunningham, 2004; Chambers et al., 2004; Kovanda and Hak, 2007).

MFA generally uses a mass balance approach to measure (i) inputs, such as domestic production and imports of raw materials; (ii) intermediate products, which require further processing; (iii) final products such as consumer goods; (iv) outputs, including wastes, direct and fugitive emissions and exports; and (v) accumulation of stock and durable goods within the economy (Sheerin, 2002). This is illustrated in Figure 1 {Insert Figure 1 here). The First Law of Thermodynamics or Law of Mass Conservation states that total inputs equal total outputs plus net accumulation of materials in the system and may be used to estimate mass balances for particular materials or within a sub-sector of the national economy (Giljum and Hubacek, 2001).

Material inputs include all solid materials, displaced by human activity, that are used in the lifecycle of a product or service or for general economic activity. Inputs may also include liquid or gaseous inputs in terms of energy flows, although these inputs tend to be less commonly accounted for. Material outputs include solid wastes, gaseous emissions (both direct and fugitive), material loads in wastewater and dissipative loss of products (Schandl et al., 2002). Stock accumulation or Net Addition to Stock (NAS) measures the physical growth rate of the economy by calculating additions to economic stocks such as physical infrastructure and durable goods (Matthews et al., 2000).

The methodology used in MFA may differ with respect to: (i) the extent that it includes 'hidden flows' or material 'rucksacks'; (ii) whether the indicator is classified as being an input, output or consumption indicator; and (iii) whether non-solid material inputs and outputs are included (EUROSTAT, 2001; Krausmann et al., 2004). Hidden flows are quantities of ancillary and excavated raw materials, which are translocated by the process of extraction but not actually used in the production of goods and services and which do not directly enter the economic system (Sheerin, 2002). Hidden flows related to foreign trade are particularly important in estimating the global environmental burden of consumption (Schandl et al., 2002).

Input indicators include (Linstead and Ekins, 2001; Sheerin, 2002; Hinterberger et al., 2003; Krausmann et al., 2004; Kovanda and Hak, 2006; Weisz et al., 2006):

1. Direct Material Input (DMI), which measures the total amount of materials which have economic value and which are directly used in production and consumption activities;
2. Total Material Input (TMI), which is DMI plus unused domestic extraction; and
3. Total Material Requirement (TMR), which measures the total direct and indirect resource requirements of all production and consumption activities, including the amount of used extraction and imports and the resulting indirect or hidden flows.

Output indicators include:

1. Domestic Processed Output (DPO), which comprises all outflows of used materials produced within the system boundary;
2. Total Domestic Output (TDO), which includes DPO and unused domestic extraction;
3. Direct Material Output (DMO), which includes DPO and total exports from the economy;
4. Total Material Output (TMO), which includes DMO and unused domestic extraction

Consumption indicators include:

1. Domestic Material Consumption (DMC), which measures the total amount of material directly consumed by the economy or apparent consumption within the system boundary. This is calculated by subtracting exports from DMI;
2. Total Material Consumption (TMC), which is the sum of DMC and indirect flows associated with imports and exports; and

3. Net Addition to Stock (NAS), which involves the gradual and incremental accumulation of materials in an economy. This can be measured by deducting DPO and total exports from DMI, i.e. NAS = DMI-DPO-Exports.

MFA may be applied on several spatial scales, including supra-national entities such as the EU, national economies, economic sectors, corporate organisations, regions or urban settlements (Brunner et al., 1994; Haberl et al., 2004). Examples of regional, urban or community MFA studies that were evaluated include those developed for regions in Switzerland (Brunner et al., 1994; Hendriks et al., 2000); Vienna (Obernosterer et al., 1998); Trinket Island (Singh et al., 2001); York (Barrett et al., 2002); the Basque Country (IHOBE, 2002); Hamburg (Hammer et al., 2003a); Singapore (Schulz, 2007); Lisbon (Niza et al., 2009); and regions in the Czech Republic (Kovanda et al., 2009). Comparative studies include those of Amann et al. (2002), which compared local communities in Bolivia, Columbia and Brazil, and the NEDS Project, which involves Hamburg, Vienna and Leipzig (Hammer et al., 2003b).

It was found that studies at the regional and local level are still very limited compared with national empirical studies and a standardised method has yet to be developed. In addition, data availability at a regional or local level may be limited for certain material or product flows and, therefore, may have to be estimated from more aggregated data using proxy factors. The two main methodological differences between national and sub-national studies are (i) how to account for import flows and (ii) the lacuna of data at a disaggregated level (Hammer et al., 2003b; Hinterberger et al., 2003). This paper attempts to address the latter by suggesting a simple and transparent way of undertaking MFA for a city-region in the absence of sufficient and robust primary data.

1.2. Dematerialisation and Decoupling

The 6th EU Environmental Action Programme (EAP) (2002-2010) emphasises the need to *inter alia* (i) decouple economic growth from environmental impact; (ii) achieve sustainable use of natural resources; (iii) increase resource efficiency or productivity; (iv) reduce energy or material intensity; (v) increase dematerialisation; and (vi) avoid unsustainable production and consumption (CEC, 2003; Vehmas et al., 2007).

One of the key policy applications of MFA is to derive indicators for resource productivity, eco-efficiency and material intensity of consumption at all levels of aggregation. These can be used to indicate progress towards dematerialisation. Absolute dematerialisation is a reduction in material throughput or energy consumption within a particular process or system over time. Relative dematerialisation is measured by the ratio between a function of environmental pressure such as material or energy consumption or generation of emissions/wastes per physical unit and an economic output measure. MFA facilitates the assessment of the material consumption of a system for a certain base year using a static approach. This allows for the evaluation of trends in material consumption through the development of time series (Niza et al., 2009).

Economic output measures are taken as a proxy for standard of living, welfare or quality of life and may include Gross Domestic Product (GDP), Gross National Income (GNI) or Gross Valued Added (GVA) (Bernardini and Galli, 1993; Cleveland and Ruth, 1999; Kovanda and Hak, 2007). Various policy targets for dematerialisation have been promulgated including the Factor 4 goal of increasing resource productivity by halving global resource requirements and its variants, i.e. Factor 2.5, which calls for an increase in productivity of non-renewable raw materials, and Factor 10 (Schmidt-Bleek, 1992; Von Weizsacker et al., 1997; Bringezu, 2003).

Decoupling is the corollary of dematerialisation. Absolute decoupling occurs when economic activities increase or remain constant while the absolute volumes of pollution or resource input decrease. Relative decoupling occurs when economic growth is accompanied by a lower growth in the environmental pressure indicator or a decrease in the economic growth is accompanied by a larger decrease in the environmental pressure indicator such as material or energy growth (Haberl et al., 2004; Kovanda and Hak, 2007). In this paper, dematerialisation will be used to refer to absolute changes in trends, while decoupling will be used to express relative changes in material or energy flows as a function of some economic parameter.

Resource efficiency may be defined as the amount of economic activity generated from material extraction/throughput or energy consumption (WBCSD, 2000). The eco-efficiency of urban material metabolism refers to the amount of social services per unit of resource consumption or per unit of pollution discharge during the process of urban material metabolism (Yan and Zhifeng, 2007). In this paper, environmental pressures caused by consumption, in this case by the residents of an Irish city-region, are measured in a time-series to (i) infer any trends in absolute dematerialisation and (ii) measure relative decoupling.

1.3. Urban Metabolism

Alberti (1996) argues that a systematic analysis of urban sustainability should consider the direct transformation of the physical structure and habitat, use of renewable and non-renewable natural resources, release of emissions and wastes and human health and well-being. In this paper, urban sustainability was assessed using biophysical indicators and the MFA framework, which measures material and waste flows. A more holistic evaluation of quality of life or ecosystem transformation could be undertaken as part of future work.

Cities appropriate the ecological output and life support functions of the global hinterland and, therefore, a prerequisite to urban development is the sustainable use of these appropriated ecosystem services (Rees and Wackernagel, 1996). This implies that, to achieve sustainable urban development, resource consumption and waste generation by the residents of a particular urban settlement should be within the carrying capacity or assimilative capacity of the regional or global hinterland.

Indeed, one could argue that ‘true’ urban sustainability implies that resources are provided for and wastes absorbed or managed by the local hinterland although in practice this is unrealistic when considering globalised city-regions. This is because these city-regions import significant quantities of materials and resource inputs to satisfy the consumption demands of the local residents and the productive capacity of local enterprise.

Human carrying capacity, which is the maximum entropic load that can safely be imposed on the natural environment, is correlated with the carrying capacity of the environment or its ‘maximum persistently supportable load’ (Rees and Wackernagel, 1996). Alternatively, it could imply that the particular urban settlement is sufficiently resilient and dynamic to adapt to material and energy fluxes and system bifurcations. This can be illustrated using MFA if resource inputs and outputs are used as part of ecological footprint (EF) analysis and compared with available biocapacity or the average per capita bioproductive land in the regional and global hinterland. This was not undertaken here although an EF analysis of natural biomass, manufactured products and construction materials and minerals has been undertaken for the same system boundary by Browne et al. (2008).

The concept of urban metabolism represents a holistic approach to urban planning and explores the interactions among resource flows, urban transformation processes, waste streams and quality of life (Wolman, 1965; Boyden et al., 1981; Douglas, 1983; Girardet, 1992; Rotmans et al., 2000). Kennedy et al. (2007, p.44) define urban metabolism as “the sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy and elimination of waste". Newman (1999) postulates that measuring urban material metabolism should include resource inputs, production and waste outputs, as well as other criteria such as amenity, health, employment, education, housing, accessibility and community. This paper focuses on measuring resource inputs and waste outputs.

Examples of urban metabolism studies that have been evaluated include Tokyo (Hanya and Ambe, 1976); Hong Kong (Newcombe et al., 1978); Sydney (Newman et al., 1996); Swiss Lowlands (Baccini, 1997); Taipei (Huang et al., 1998); Vienna (Hendriks et al., 2000), Hong Kong (Warren-Rhodes and Koenig, 2001); Greater London (Chartered Institute of Wastes Management, 2002); Cape Town (Gasson, 2002); Shenzhen City in China (Yan and Zhifeng, 2007); and Lisbon (Niza et al., 2009). This paper aims to add to the literature on urban metabolism and identify trends and data gaps by measuring material flows in an Irish city-region.

2. Methodology

The city-region selected was Limerick City and its environs, which is the primary urban centre in the Mid-West region in the Republic of Ireland. The population of Limerick City and its environs increased by 10% from 79,137 in 1996 to 86,998 in 2002 (CSO, 2007a). The system boundary includes the municipal borough as well as six District Electoral Divisions (DEDs), which are taken to include the environs of the city-region. Population figures were taken from official Irish Central Statistics Office (CSO) publications with intercensal population statistics estimated by interpolation.

This case study was selected as part of a wider research project, which aimed to (i) apply a number of methods to an Irish settlement to measure sustainable urban development; (ii) evaluate data availability for developing an ‘urban sustainability toolkit’ for Ireland; and (iii) assess commonalities and differences across different sustainability metrics (Browne, 2007). In order to complete a material flow analysis for the study area and assess urban metabolism, it was necessary to quantify: (a) extraction, imports and exports of raw materials; (b) manufactured good production and trade; (c) waste production and methods of waste management; and (d) energy balances and emissions. Consumption was calculated by estimating the sum of production and imports minus exports. The MFA approach adopted is that recommended by the EUROSTAT methodological guide for material flows (EUROSTAT, 2001; Bringezu and Schutz, 2001). A number of MFA indicators are applied to the Limerick city-region, including input, output and consumption indicators.

The MFA approach proposed by Bringezu and Schutz (2001) suggests calculating upstream indirect or hidden flows associated with production and imports. Indirect flows include used or unused material produced during material extraction and/or excavation. In this paper, hidden flows associated with production were estimated from domestic waste production while hidden flows associated with imports were estimated from coefficient multipliers and import flows. These multipliers are expressed in units of tonne/tonne (Bringezu and Schutz, 2001).

Material flow data, in weight terms, were collated for the period 1992-2002 for:

1. Domestic extraction, imports and exports of agricultural and marine biomass; forestry products; solid, liquid and gaseous fossil fuels, including coal, lignite, peat, oil, petroleum products and natural gas; metalliferous ores, waste and scrap metal; and construction materials and other crude minerals.
2. Unused domestic extraction and waste, including agriculture, aquaculture and food processing; wood biomass and wood processing; leather and textiles; petroleum refining and natural gas purification; construction and demolition (C & D) waste; and mining and quarrying.
3. Hidden flows associated with imports of raw materials, which are calculated using hidden flow coefficients and import data, and
4. Material outputs, including household, commercial and industrial waste, greenhouse gas (GHG) emissions and acidifying gases. Material outputs may also include dissipative flows although these were not included here.

Material production and trade data were collated for Standard International Trade Classification (SITC) Divisions 00-43 from the Irish CSO. Most material flow input and consumption data were only available at a national level and, in order to account for material flows in the Limerick city-region, a number of proxies had to be used, including population ratios, average household expenditure, employee numbers, ratios of construction activity and industrial output.

This was necessary due to gaps in available primary data for the Limerick city-region and the difficulty in measuring bottom-up flows for an urban conurbation of that magnitude over the given time-series. The purpose of proxy factors and ratios is to adjust national data, where regional or local data are not available, by estimating what the potential local contribution might be on the basis of a scaled ratio. This was done using expenditure as a proxy for relative consumption and employee numbers as a proxy for relative industrial production or commercial services. Thus, national data were disaggregated on a per capita basis and then adjusted accordingly using proxy factors.

Average weekly Limerick household and national expenditure on food and manufactured household goods, including clothing/textiles, household durable and non-durable goods and miscellaneous paper and other items, was taken from the 1999-2000 National Household Budget Survey (NHBS) micro-data and is shown in Table 1 {Insert Table 1 here}. This was used to estimate expenditure ratios or proxies, which were then used to estimate per capita consumption of goods by Limerick residents.

The expenditure proxy ratio for household durable goods was used for metallic products and other manufactured goods as well as wood products and furniture. Population proxies were used for industrial machinery and equipment, transport machinery and equipment and non-residential construction materials and non-metallic mineral products. Total house completions in Limerick Borough and County and nationally were used to estimate the amount of residential construction in Limerick relative to national residential construction. The residential construction proxy was used to estimate residential material consumption by Limerick residents while the population proxy was used to estimate materials consumed in other forms of construction, including private non-residential construction, productive and social infrastructure.

Average weekly expenditure on residential fuel and electricity and motor fuel is also given in Table 1 {Insert Table 1 here}. Residential and transport energy use was adjusted according to average weekly expenditure on such items by Limerick residents relative to national average expenditure. Thus, for example, it was found that £17.84 were spent weekly by an average household in Limerick City on residential fuel in that study period, compared with £21.68 spent weekly by an average Irish household (CSO, 2002). Therefore, a ratio of 0.82 was used to adjust national average residential energy use.

Similarly, it was found that £15.47 were spent weekly by a household in Limerick City on motor fuel, compared with £17.13 spent weekly by an average Irish household (CSO, 2002). Therefore, a ratio of 0.9 was used to adjust national average transport energy use. It was assumed that these ratios applied over the case study time period. Per capita consumption was scaled up using the population of Limerick City and its environs to estimate total consumption in the city-region.

The material flow data were used to estimate consumption in the residential, commercial and public services, industry and transport sectors. All material flows, which indirectly relate to material or product consumption, were included, for example mining and agriculture, even though some of these flows may occur outside the jurisdictional boundary of the Limerick city-region. This is in accordance with the principle of consumer responsibility, when measuring environmental impact of urban residents, as opposed to geographical or territorial responsibility. Expenditure ratio proxy factors were used as they indicate the relative scale of local consumption to the national average.

Hidden flows were estimated for both domestic production and imports. Hidden flow coefficient multipliers were collated from a number of sources and were used to estimate hidden flows associated with material imports in order to give an estimate of the impacts of material extraction resulting from resource consumption in the city-region. Hidden flow coefficient multipliers were taken from international estimates for hard coal, brown coal/lignite, natural gas extraction, crude oil, peat, metals, biomass, construction materials and minerals (Bringezu and Schutz, 2001). These multipliers were used to estimate hidden flows associated with imports in order to determine the TMR for 1996 and 2002.

Hidden flows associated with resources produced domestically were estimated from Irish Environmental Protection Agency (EPA) National Waste Database Reports and were used to estimate TMI for 1996 and 2002. Data were also collated for the main waste streams, including household, commercial and industrial waste, as well as a number of ‘priority’ waste streams, such as C & D waste, healthcare waste, waste oils, packaging waste, waste batteries, waste sludges, waste from electrical and electronic equipment (WEEE), polychlorinated biphenyls (PCB), scrap metals, end of life vehicles and scrap tyres.

National data for total final consumption (TFC) of energy in Ireland were collated from International Energy Agency (IEA) reports and proxies were used to disaggregate to settlement-specific data. Employee number proxies were used to estimate commercial and industrial energy consumption in the Limerick city-region. Population and expenditure proxies were applied to other sectoral energy uses, including residential and transport energy usage.

Material indicator trends were then calculated for the period 1992-2002, including DMI, DMC, DPO and DMO. Other indicators were calculated for 1996 and 2002, including TMC, TMI, TMR, TDO and TMO. These indicators were calculated for 1996 and 2002 due to data availability in those years. Long-term trends were not estimated for TMC, TMI, TMR, TDO and TMO due to the data requirements involved in estimating hidden flows. This paper applies a static approach to measuring annual material and waste flows in a time series and the results focus on the input and process output stages of the mass balance, as illustrated in Figure 1 {Insert Figure 1 here}.

3. Results

Material input and consumption data were used to calculate DMC and DMI across a number of sectors, including agricultural and marine biomass, forestry and wood products, fossil fuels, metalliferous ores, construction materials and other crude minerals. It was found that total DMC by Limerick residents increased by 83% from 1,070,300 tonnes in 1992 to 1,961,800 tonnes in 2002, as can be seen in Tables 2 and 3 {Insert Tables 2 and 3 here}. This accounts for raw material consumption used for intermediate or finished manufactured products. DMC per capita increased by 60% from 14.1 tonnes in 1992 to 22.6 tonnes in 2002, as can be seen in Figure 2 {Insert Figure 2 here}. The increase in DMC per capita is possibly due to increased disposable income, increases in industrial production, changes in consumption patterns or increased consumption of construction materials.

Total DMI increased by 64% from 1,500,900 tonnes in 1992 to 2,468,300 tonnes in 2002, as can be seen in Tables 2 and 3. DMI per capita increased by 44% from 19.7 tonnes in 1992 to 28.4 tonnes in 2002, as can be seen in Figure 3. The decrease between 1999 and 2000 for both DMC and DMI per capita is a result of reduced manufacturing employee numbers and, therefore, a lower employee number ratio proxy. It can be seen that DMC increased at a faster rate than DMI, possibly as a result of greater domestic consumption compared with material extraction for exports as raw materials, intermediate and finished goods {Insert Figure 3 here}.

Municipal waste in Limerick is estimated to have increased by 116% from 38,500 tonnes in 1992 to 83,100 tonnes in 2002, as can been in Tables 4 and 5. Municipal waste per capita increased by 87% from 0.51 tonne per capita in 1992 to 0.96 tonne per capita in 2003. Total waste, which consists of municipal waste, industrial waste and other waste streams, increased by 35% from 208,500 tonnes in 1992 to 282,100 tonnes in 2002. Total waste generated per capita increased by 20% from 2.7 tonnes per capita in 1992 to 3.2 tonnes in 2003, as can be seen in Tables 4 and 5 {Insert Tables 4 and 5 here}.

Thus it can be seen that both total municipal waste and municipal waste per capita increased at a faster rate than DMC and DMC per capita, respectively, which indicates that policies have not been successful in decoupling municipal waste generation from material consumption. However, the increase in total waste and total waste per capita was slower than the increase in DMC and DMC per capita, respectively, which indicates that total waste generation has been decoupled from material consumption. This may be because industrial production and the construction sectors are more efficient in waste processing than household or commercial consumption and waste production.

It was found that TMI increased by 33% from 2,036,400 tonnes in 1996 to 2,702,200 tonnes in 2002. TMI per capita increased by 21% from 26 tonnes to 31 tonnes, as can be seen in Table 6. Hidden flows associated with domestic production represented 9% of TMI in 1996 and 2002. TMR increased by 26% from 2,714,100 tonnes in 1996 to 3,422,100 tonnes in 2002. TMR per capita increased by 15% from 34 tonnes in 1996 to 39 tonnes in 2002, as can be seen in Table 6. Hidden flows associated with imports represented 25% of TMR in 1996 and 21% of TMR in 2002. This suggests that hidden flows associated with domestic production are relatively lower than hidden flows associated with imports, although the proportion of hidden flows associated with imports to TMR did fall between 1996 and 2002 {Insert Table 6 here}.

TFC of energy by Limerick residents increased by 60% from 125,300 tonnes of oil equivalent (TOE) in 1992 to 200,300 TOE in 2002. TFC per capita increased by 35% from 1.7TOE in 1992 to 2.3TOE in 2002 (IEA, 2000, 2004). Total air emissions, including GHG emissions, ammonia (NH_3), nitrogen oxides (NO_X), sulphur dioxide (SO_2) and volatile organic compounds (VOCs), generated by Limerick residents from all sources, increased by 40%

from 700,300 tonnes in 1992 to 983,000 tonnes in 2002, as can be seen in Tables 7 and 8. Total air emissions generated per capita were estimated to have increased by 23% from 9.2 tonnes in 1992 to 11.3 tonnes in 2002 {Insert Tables 7 and 8 here}.

DPO per capita of Limerick residents increased by 22% from 11.9 tonnes in 1992 to 14.5 tonnes in 2002, as can be seen in Tables 7 and 8. This should be compared with DMC per capita and DMI per capita, which increased by 60% and 44%, respectively, over the same period. This suggests that output indicators are increasing at a relatively slower rate than input and consumption indicators, which suggests accumulation of materials within the system boundary and slower dissipation of waste materials. DMO per capita increased by 19% from 14.8 tonnes in 1992 to 17.6 tonnes in 2002, as can be seen in Tables 7 and 8. Changes in per capita DPO and DMO per annum for the period 1992 to 2002 are shown in Figure 4 {Insert Figure 4 here}.

The TDO, which is the sum of DPO and unused extraction or hidden flows associated with production, was estimated to have increased by 25% from 1,196,600 tonnes in 1996 and 1,499,000 tonnes in 2002. TDO per capita per annum increased by 14% from 15.1 in 1996 to 17.2 tonnes in 2002. The TMO, which is the sum of TDO and physical exports, was estimated to have increased by 22% from 1,442,300 tonnes in 1996 and 1,761,100 tonnes in 2002. TMO per capita per annum increased by 11% from 18.2 tonnes in 1996 to 20.2 tonnes in 2002.

Material exports in 1996 were 14.3% of production and hidden flows associated with exports were 25,720 tonnes. Therefore, TMC, which is TMR minus exports and their associated hidden flows, was estimated to be 2,492,200 tonnes in 1996. Material exports in 2002 were 13.4% of production and hidden flows associated with exports were 31,266 tonnes. Therefore, TMC in 2002 was 3,152,400 tonnes. Thus, TMC per capita per annum increased by 15% from 31.5 tonnes in 1996 to 36.2 tonnes in 2002.

NAS was calculated by deducting DPO and total exports from DMI. Thus, it was estimated that NAS increased by 58% from 594,084 tonnes in 1996 to 941,101 tonnes in 2002. This indicates that, although DMC per capita increased by 28% between 1996 and 2002 and DMI per capita increased by 21% in the same period, the NAS increased by a faster rate, indicating a greater accumulation of stock in the local economy over that period.

MFA indicators may also be compared with personal disposable income per capita, total income per capita and GVA in order to determine whether consumption is being decoupled from economic growth. It was found that DMC per capita Limerick resident increased by 28% from 17.7 tonnes in 1996 to 22.6 tonnes in 2002 and DMI per capita increased by 21% from 23.5 tonnes in 1996 to 28.4 tonnes in 2002, as can be seen in Tables 2 and 3. DPO per capita increased by 13% from 12.8 tonnes per capita in 1996 to 14.5 tonnes per capita in 2002, as can be seen in Tables 7 and 8.

This compares with a 77% increase in disposable income by Limerick residents in the same period, from €9,768 per capita in 1996 to €17,247 in 2002, which indicates relative decoupling of material and waste flow indicators from economic growth. In addition, GVA per capita increased by 105% from €14,668 in 1996 to €30,029 in 2002, which also indicates relative decoupling (CSO, 2006). This suggests that, although material consumption and process outputs have increased in the Limerick city-region over the study period, disposable income and GVA per capita have increased at faster rates.

4. Discussion and Conclusions

In this paper, MFA of an Irish city-region was undertaken in order to calculate trends for a number of indicators over a particular time-series. In this context, the policy objective is to estimate whether material consumption is reducing in absolute terms or whether there is decoupling of consumption or waste from economic growth. It was found that, although both DMC and DMI per capita increased between 1992 and 2002, the increase in total waste and total waste per capita was slower, which indicates that total waste generation has been decoupled from material consumption. It can be seen in Figures 2 and 3 that per capita consumption and material input are increasing over the study period, indicating that the city-region is not dematerialising in absolute terms. The decrease between 1999 and 2000 and subsequent increase is a result of a large increase in construction output in 1999 and subsequent decrease in 2000. Trends are also affected by fluctuating employee numbers.

This definition of dematerialisation relates solely to a quantitative measure of resource demands and waste production and does not relate consumption or output indicators to the resilience or carrying capacity of the local, regional or global hinterland. Possible future work could involve comparing per capita indicators with an equitable allocation of resources, either global or national, or with the available bioproductive or assimilative capacity of the regional or global hinterland. Thus, MFA can also be used to compare consumption trends with carrying capacity, environmental space or critical natural capital, if resource inputs are converted into an assessment of the demands on bioproductive capacity (Bartelmus, 2003; Ekins et al., 2003).

The research shows the difficulty in undertaking a regional or urban material flow analysis, particularly in an Irish context. Material and product consumption data had, in most cases, to be disaggregated from national data using proxy factors, although settlement-specific municipal waste data were used. This reflects a disparity in data availability between different countries with some statistical organisations collating disaggregated regional material extraction and consumption data. Niza et al. (2009, p.384) point out that “urban metabolism studies have been established for only a few cities worldwide, and difficulties obtaining adequate statistical data are universal”.

This research was an attempt to apply standard MFA accounting practice to an Irish case-study. Comparison between national and city-region MFA indicators is hindered as largely national data and population proxies were used. However, some comparison can be made, e.g. O’Leary and Cunningham (2004) estimate that DMI per capita in Ireland in 2000 was 39 tonnes, DMC per capita was 35.5 tonnes, DPO per capita was 30.7 tonnes and DMO per capita was 34.2 tonnes. This compares with figures for Limerick for 2000 as estimated in this paper, including DMI per capita of 27.1 tonnes, DMC per capita of 20.7 tonnes, DPO per capita of 15 tonnes and DMO per capita of 18 tonnes.

Thus, it can be seen that the average figures for Limerick are considerably less than the national averages. This is reflected in the expenditure proxies as can be seen in Table 1, which indicate that residential energy and transport fuel consumption by Limerick residents were lower than the average consumption. This may be due to economies of scale and higher public transport use or walking and cycling in an urban area.

The Limerick results may also be compared with figures for city-regions in other jurisdictions. For example, CIWM (2002) estimates that the average consumption of materials in London in 2000 was about 6.7 tonnes per capita per annum, while average figures for the UK and the Isle of Wight are about 6.13 tonnes per capita and 5.49 tonnes per capita, respectively. This compares with average DMC per capita by Limerick residents of 20.7 tonnes per capita in 2000. This is possibly as a result of a greater proportion of materials consumption for construction in the Limerick area.

In addition, it may also be a result of different accounting or mass balance methods, for example by scaling national production using proxy factors rather than accounting for actual production in the city-region area using the ‘territorial principle’. Average waste generated in London was 3.56 tonnes per capita in 2000, which compares with an average figure for Limerick of 3.7 tonnes per capita in 2000. Thus, although average DMC per capita for Limerick residents is considerably higher than the UK or London averages, waste output is similar, which suggests a greater accumulation of stock or waste prevention.

Niza et al. (2009) have found that annual material consumption in Lisbon in 2004 was 11.223 million tonnes or 20 tonnes per capita and material output was 2.149 million tonnes or 3.84 tonnes per capita. This compares with average DMC per capita for Limerick residents of 22.6 tonnes in 2002 and total waste generated per capita of 3.2 tonnes, as can be seen in Tables 3 and 5, respectively. Thus, it can be seen that material consumption and waste production are broadly similar in both studies, although the timeframe for the Lisbon study is beyond the timeframe used in this paper.

IHOBE (2002) estimates that the average DMI per capita in the Basque Country in 1997 was 23.35 tonnes per capita and compares this with Italy (15 tonnes per capita), the UK (19 tonnes per capita), the EU-15 average (26.07 tonnes per capita), Ireland (35 tonnes per capita) and Finland (39 tonnes per capita). DMI per capita for Limerick residents in 1997 was 26.6 tonnes per capita, as can be seen in Table 2. This indicates that the per capita DMI for Limerick residents in 1997 was about equivalent to the EU-15 average and slightly higher than the Basque country average but considerably lower than the national average. It is worth noting that the national DMI per capita in Ireland, as estimated by IHOBE (2002), was the second highest in the EU-15 behind Finland.

Weisz et al. (2006) estimate that the average DMC per capita in 2000 for the EU-15 was 15.7 tonnes per capita, including 4 tonnes per capita for biomass, 7 tonnes per capita for construction minerals, 1 tonne per capita for industrial minerals and ores and 3.7 tonnes per capita for fossil fuels. Average DMI per capita was estimated to be 16.8 tonnes per capita. The average DMC per capita for Ireland in 2000 was estimated to be 24.4 tonnes per capita, including 10.6 tonnes per capita for biomass, 7.2 tonnes per capita for construction minerals, 2 tonnes per capita for industrial minerals and ores and 4.6 tonnes per capita for fossil fuels. Total DMI per capita for Ireland was estimated to be 27.3 tonnes per capita. This suggests that the national figures for Ireland derived by Weisz et al. (2006) are similar to the figures for the Limerick city-region found in this study, i.e. 20.7 tonnes per capita for DMC and 27.1 tonnes per capita for DMI, as can be seen in Tables 2 and 3.

In addition, the results in this paper can be compared to a similar study undertaken for the same system boundary by Browne et al. (2009). This paper aimed to measure product and waste flows in the Limerick city-region using the principles of metabolism and mass balance. An empirical indicator to measure resource efficiency, using a ratio of waste disposal as a function of product consumption, was developed and it was found that total materials metabolic inefficiency fell by 31% from 0.13 in 1996 to 0.09 in 2002. This suggests that waste production as a function of product consumption fell between 1996 and 2002, indicating that there is relative decoupling of waste from product consumption.

The results shown in this paper can be differentiated from Browne et al. (2009) in that (i) they illustrate similar trends using standard MFA indicators rather than attempting to relate waste flows to product consumption and (ii) they include raw material flows, whereas the metabolic flows shown in Browne et al. (2009) include product flows in the form of final goods. This paper, therefore, extends the material flow analysis to the full life cycle from extraction of raw materials to final disposal.

MFA indicators may also be used concomitantly with macro-economic indicators such as Gross Domestic Product (GDP), Gross National Income (GNI), disposable income per capita or Gross Added Value (GVA) in order to determine trends in relative decoupling. For instance, Vehmas et al. (2007) found that the general trend in the EU over the period 1980-2000 is weak delinking, i.e. increasing DMI but decreasing material intensity of production, that is DMI as a function of GDP. In Ireland, it was found that, despite a 50% decrease in material intensity, DMI increased by 30% between 1980 and 2000, which may be explained by the fact that the Irish GDP increased by 250% between 1980 and 2000, compared with an average EU growth of 40% in the same period. This supports the results found in this paper, which indicate that, although DMC per capita and DMI per capita increased over the study period, disposable income increased at a faster rate.

Canas et al. (2003) argue that DMI is characterized by a plateau and found that there is no evidence of either quadratic or cubic behavior for GDP higher than the income threshold level. Indeed, some transitional economies, such as Portugal, show sharp increases in material consumption as incomes rise. This is due to an increase in consumption of construction materials and the strengthening of the critical infrastructure required to improve transportation and housing. Niza and Ferrao (2006) argue, however, that as a traditional economy evolves the higher growth rates in the construction sector attenuate and the services sector becomes dominant. Weisz et al. (2006) argue that a distinguishing characteristic of DMC of construction minerals is its volatility with economic growth and found that the trend of DMC of construction minerals over the past three decades corresponds better with economic growth than the domestic material consumption trends of any other material type.

The results for the Limerick city-region also indicate high volumes of residential and non-residential construction and infrastructure, although this may be expected to stabilise over a longer time-series. Indeed, it can be seen that the almost linear trend in both DMC per capita and DMI per capita between 1992 and 2000 has stabilized in the period between 2000 and

2002 and indeed both DMC and DMI per capita fell between 2001 and 2002. However, this is not a sufficient time series to infer whether this is likely to be a long-term trend.

This research shows that, even if relative decoupling is achieved, if resource throughput and material consumption continue to increase, then increases in recycling and recovery rates will only partially mitigate the problem and, therefore, material inputs need to be reduced at source and incentives should be in place to ensure more sustainable personal and household consumption. The lack of data availability limited the inferences that can be drawn from the results with regards to local sustainability in the particular case-study and part of future work should involve a bottom-up assessment to test the methodology.

Future work should also focus on the potential impact of the recent economic downturn in Ireland on material production and waste generation and evaluate how closely correlated these material flow indicators are to economic growth. Recent data for 2008 indicate that national domestic extraction fell by 40% from 205.6 million tonnes in 2007 to 124.2 million tonnes in 2008, while national material imports fell by 8% from 41.4 million tonnes in 2007 to 38.1 million tonnes in 2008. In particular, there was a sharp decrease of 51% in domestic extraction of non-metallic minerals from 162.1 million tonnes in 2007 to 80.0 million tonnes in 2008. In 2008, there was a net accumulation of 86.8 million tonnes of material in the Irish economy, compared with 172.0 million tonnes in 2007 (CSO, 2010).

DMI in 2008 is the same level now as it was in 1999. DMC is slightly less at 147.0 million tonnes, compared with 150.8 million tonnes in 1999. In the same period, GDP rose by 55% at constant prices. Material intensity (DMC/GDP) fell by 36% (CSO, 2010). This suggests that more recently there has been absolute decoupling of material consumption, possibly as a direct result of the decline in construction activity. It would be useful as part of future work to establish whether these trends are mirrored in the Limerick city-region and to establish whether this is likely to be a medium to long-term trend.

Other potential work could involve a comparison with an evaluation of top-down national MFA. This would indicate the extent of correlation between aggregated and disaggregated MFA and the impact of using ratios and proxy factors. It is concluded that this paper is innovative as it (i) builds on the literature on urban metabolism and regional MFA; (ii) identifies data gaps in the Irish context by attempting to apply standard MFA to an Irish city-region; and (iii) attempts to disaggregate top-down data to infer trends in MFA indicators and assess relative decoupling.

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Tables and Figures

Sector	Limerick Average Expenditure (£)	National Expenditure	Ratio
Food	80.78	93.6	0.86
Clothing and Textiles	38.07	35.11	1.08
Paper and Printed Material	8.42	8.33	1.01
Non-Durable Household Goods and Miscellaneous Plastic Products	26.93	33.49	0.81
Household Durable Goods	20.79	26.86	0.77
Total Manufactured Goods	94.21	103.79	0.91
Residential Fuel and Electricity	17.84	21.68	0.82
Motor Fuel	15.47	17.13	0.9

Table 1: Average Weekly Household Expenditure (CSO, 2002)

	1992	1993	1994	1995	1996	1997
Domestic Material Consumption (DMC)	1,070,259	1,112,936	1,264,530	1,329,624	1,402,029	1,669,859
Production	1,107,083	1,109,627	1,248,363	1,387,476	1,374,150	1,623,508
Imports	393,856	410,481	446,944	469,715	482,081	514,275
Direct Material Input (DMI)	1,500,939	1,520,108	1,695,307	1,857,191	1,856,231	2,137,783
Population	76,176	76,916	77,657	78,397	79,137	80,447
DMC Per Capita	14.1	14.5	16.3	17	17.7	20.8
DMI Per Capita	19.7	19.8	21.8	23.7	23.5	26.6

Table 2: DMC and DMI by Limerick Residents, 1992-1997 (Tonnes per Annum)

	1998	1999	2000	2001	2002
Domestic Material Consumption (DMC)	1,814,241	2,098,628	1,746,762	1,988,551	1,961,764
Production	1,720,706	2,020,119	1,659,488	1,872,000	1,784,273
Imports	511,448	616,968	622,894	670,451	684,038
Direct Material Input (DMI)	2,232,154	2,637,087	2,282,382	2,542,451	2,468,311
Population	81,757	83,067	84,377	85,867	86,998
DMC Per Capita	22.2	25.3	20.7	23.2	22.6
DMI per Capita	27.3	31.8	27.1	29.6	28.4

Table 3: DMC and DMI by Limerick Residents, 1998-2002 (Tonnes per Annum)

	1992	**1993**	**1994**	**1995**	**1996**	**1997**
Municipal Waste	38,478	41,299	44,653	48,356	52,782	57,968
Industrial Waste	134,786	130,826	140,424	141,778	143,782	156,583
Construction and Demolition (C & D) Waste	11,735	13,218	14,889	16,770	18,890	21,277
Healthcare Waste	9	13	18	26	37	53
Packaging Waste	10,014	11,066	12,227	13,511	14,929	16,496
Scrap Metal Waste from End-of-Life Vehicles	749	683	957	1,027	1,105	1,194
Scrap Tyres	1,911	2,037	2,170	2,313	2,465	2,626
Battery Waste	155	167	179	190	230	270
Waste from Electrical and Electronic Equipment (WEEE)	727	752	819	891	978	981
Waste Oils and Oily Sludge	157	154	151	148	146	143
Sewage and Industrial Sludge	9,773	9,911	10,057	10,212	10,350	10,550
Total	**208,496**	**210,125**	**226,545**	**235,223**	**245,693**	**268,142**
Population of Limerick and its Environs	76,176	76,916	77,657	78,397	79,137	80,447
Total Waste Generated per Capita	**2.7**	**2.7**	**2.9**	**3**	**3.1**	**3.3**

Table 4: Total Waste Generated in Limerick City and its Environs, 1992-1997 (Tonnes Per Annum) (Carey et al., 1996; Crowe et al., 2000; Meaney et al., 2003; Collins et al., 2004a; Collins et al., 2004b; Collins et al., 2005)

	1998	**1999**	**2000**	**2001**	**2002**
Municipal Waste	64,064	70,197	77,254	75,783	83,090
Industrial Waste	162,846	162,577	166,134	108,225	120,536
C & D Waste	23,966	26,655	29,344	32,030	35,624
Healthcare Waste	76	99	122	146	189
Packaging Waste	18,228	19,959	21,691	23,307	24,007
Scrap Metal Waste from End-of-Life Vehicles	1,235	1,736	2,119	1,561	1,303
Scrap Tyres	2,799	2,971	3,144	3,316	3,520
Battery Waste	350	390	447	431	522
Waste from Electrical and Electronic Equipment (WEEE)	1,061	1,249	1,325	1,478	1,692
Waste Oils and Oily Sludge	140	137	135	129	127
Sewage and Industrial Sludge	10,735	10,919	11,113	11,288	11,503
Total	**285,500**	**296,891**	**312,826**	**257,694**	**282,112**
Population of Limerick and its Environs	81,757	83,067	84,377	85,867	86,998
Total Waste Generated per Capita	**3.5**	**3.6**	**3.7**	**3**	**3.2**

Table 5: Total Waste Generated in Limerick City and its Environs, 1998-2003 (Tonnes Per Annum) (Carey et al., 1996; Crowe et al., 2000; Meaney et al., 2003; Collins et al., 2004a; Collins et al., 2004b; Collins et al., 2005)

	1996	**2002**
Direct Material Input (DMI)	1,856,231	2,468,311
Hidden Flows Associated with Domestic Production	180,151	233,918
Total Material Input (TMI)	2,036,382	2,702,229
Population of Limerick and its Environs	79,137	86,998
TMI Per Capita	**26**	**31**
Hidden Flows Associated with Imports	677,713	719,912
Total Material Requirement (TMR)	2,714,095	3,422,141
TMR Per Capita	**34**	**39**

Table 6: Total Material Input (TMI) and Total Material Requirement (TMR) for Limerick City and its Environs, 1996 and 2002 (Tonnes per Annum)

	1992	1993	1994	1995	1996	1997
Total Waste Generated	208,496	210,125	226,545	235,223	245,693	268,142
Total Air Emissions	700,296	694,285	722,231	740,864	770,785	821,069
Domestic Processed Output (DPO)	908,792	904,410	948,776	976,087	1,016,478	1,089,211
Population	76,176	76,916	77,657	78,397	79,137	80,447
DPO Per Capita	11.9	11.8	12.2	12.5	12.8	13.5
National Physical Exports	10,347,793	9,966,296	10,085,614	10,790,051	11,269,195	11,411,458
Population Proxy	0.021	0.022	0.022	0.022	0.022	0.022
Physical Exports for Limerick Residents	222,271	214,973	218,414	234,576	245,669	249,797
Direct Material Output (DMO)	1,131,062	1,119,383	1,167,190	1,210,663	1,262,147	1,339,008
DMO Per Capita	14.8	14.6	15	15.4	16	16.6

Table 7: DPO and DMO of Limerick Residents, 1992-1997 (Tonnes per Annum)

	1998	1999	2000	2001	2002
Total Waste Generated	285,500	296,891	312,826	257,694	282,112
Total Air Emissions	867,649	910,655	949,590	1,000,771	982,952
Domestic Processed Output (DPO)	1,153,149	1,207,546	1,262,416	1,258,465	1,265,064
Population	81,757	83,067	84,377	85,867	86,998
DPO Per Capita	14.1	14.5	15	14.7	14.5
National Physical Exports	11,991,886	11,682,097	11,642,647	12,034,098	11,803,067
Population Proxy	0.022	0.022	0.022	0.022	0.022
Physical Exports for Limerick Residents	263,342	257,006	257,163	267,157	262,146
Direct Material Output (DMO)	1,416,491	1,464,552	1,519,579	1,525,622	1,527,210
DMO Per Capita	17.3	17.6	18	17.8	17.6

Table 8: DPO and DMO of Limerick Residents and Per Capita, 1998-2003 (Tonnes per Annum)

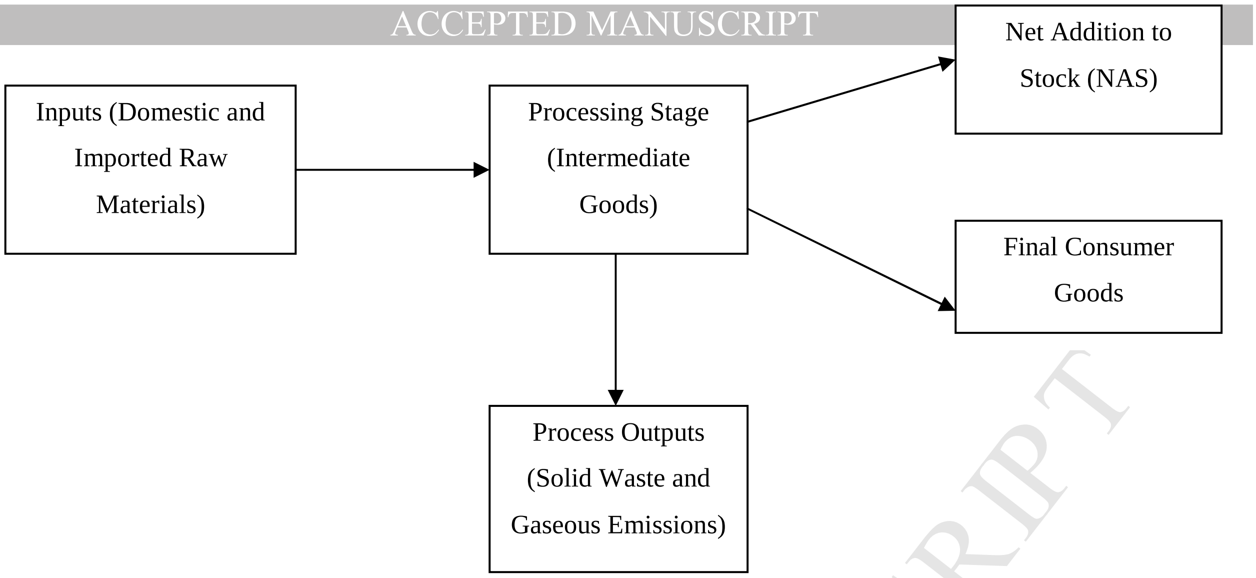

Figure 1: Mass Balance Schematic

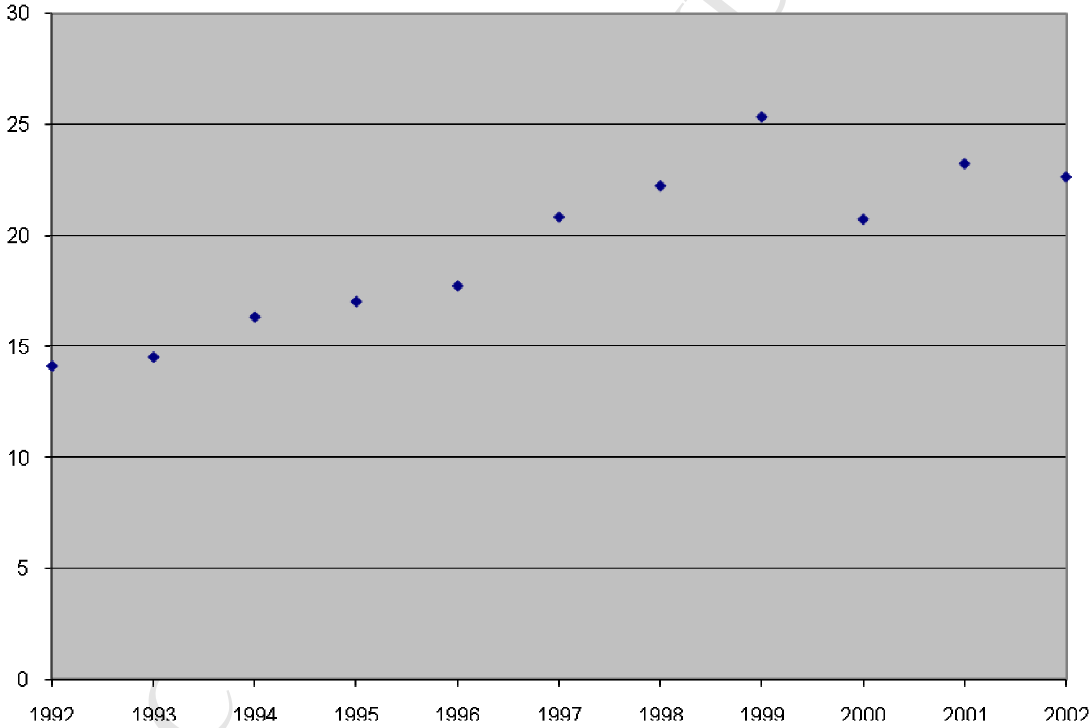

Figure 2: DMC per capita of Limerick residents, 1992-2002 (Tonnes)

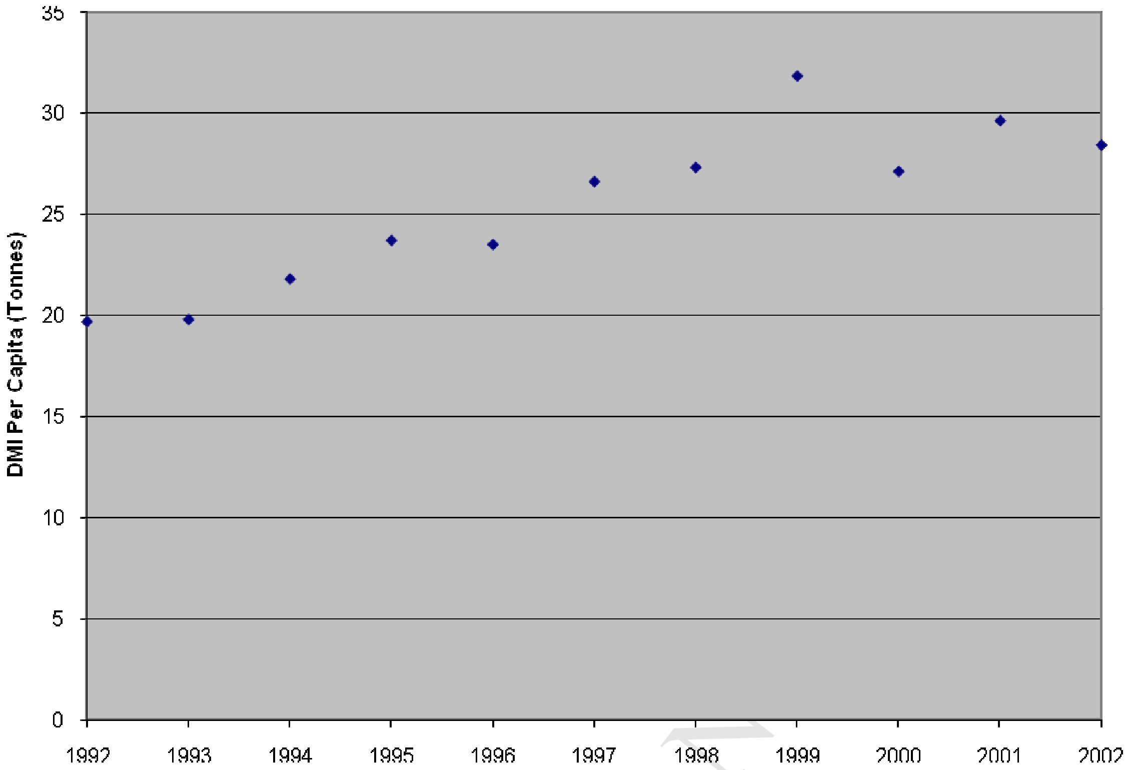

Figure 3: DMI per capita of Limerick residents, 1992-2002 (Tonnes)

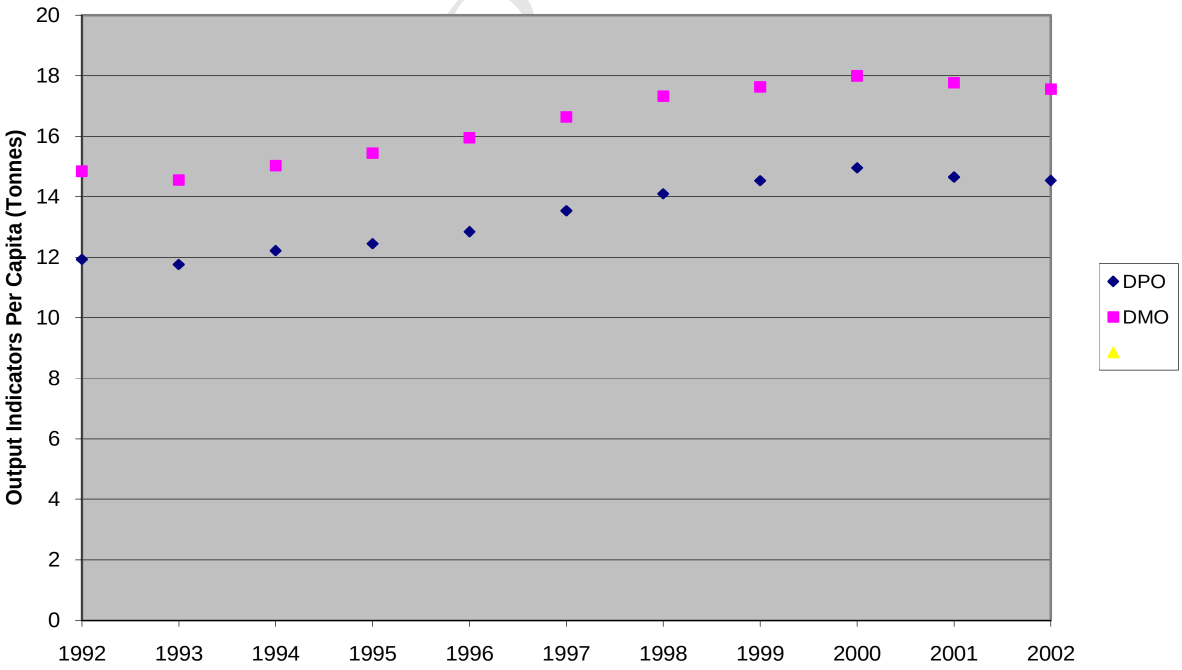

Figure 4: DPO and DMO Per Capita of Limerick Residents 1992-2002 (Tonnes)

Tables and Figures

Sector	Limerick Average Expenditure (£)	National Expenditure	Ratio
Food	80.78	93.6	0.86
Clothing and Textiles	38.07	35.11	1.08
Paper and Printed Material	8.42	8.33	1.01
Non-Durable Household Goods and Miscellaneous Plastic Products	26.93	33.49	0.81
Household Durable Goods	20.79	26.86	0.77
Total Manufactured Goods	94.21	103.79	0.91
Residential Fuel and Electricity	17.84	21.68	0.82
Motor Fuel	15.47	17.13	0.9

Table 1: Average Weekly Household Expenditure (CSO, 2002)

	1992	1993	1994	1995	1996	1997
Domestic Material Consumption (DMC)	1,070,259	1,112,936	1,264,530	1,329,624	1,402,029	1,669,859
Production	1,107,083	1,109,627	1,248,363	1,387,476	1,374,150	1,623,508
Imports	393,856	410,481	446,944	469,715	482,081	514,275
Direct Material Input (DMI)	1,500,939	1,520,108	1,695,307	1,857,191	1,856,231	2,137,783
Population	76,176	76,916	77,657	78,397	79,137	80,447
DMC Per Capita	14.1	14.5	16.3	17	17.7	20.8
DMI Per Capita	19.7	19.8	21.8	23.7	23.5	26.6

Table 2: DMC and DMI by Limerick Residents, 1992-1997 (Tonnes per Annum)

	1998	1999	2000	2001	2002
Domestic Material Consumption (DMC)	1,814,241	2,098,628	1,746,762	1,988,551	1,961,764
Production	1,720,706	2,020,119	1,659,488	1,872,000	1,784,273
Imports	511,448	616,968	622,894	670,451	684,038
Direct Material Input (DMI)	2,232,154	2,637,087	2,282,382	2,542,451	2,468,311
Population	81,757	83,067	84,377	85,867	86,998
DMC Per Capita	22.2	25.3	20.7	23.2	22.6
DMI per Capita	27.3	31.8	27.1	29.6	28.4

Table 3: DMC and DMI by Limerick Residents, 1998-2002 (Tonnes per Annum)

	1992	**1993**	**1994**	**1995**	**1996**	**1997**
Municipal Waste	38,478	41,299	44,653	48,356	52,782	57,968
Industrial Waste	134,786	130,826	140,424	141,778	143,782	156,583
Construction and Demolition (C & D) Waste	11,735	13,218	14,889	16,770	18,890	21,277
Healthcare Waste	9	13	18	26	37	53
Packaging Waste	10,014	11,066	12,227	13,511	14,929	16,496
Scrap Metal Waste from End-of-Life Vehicles	749	683	957	1,027	1,105	1,194
Scrap Tyres	1,911	2,037	2,170	2,313	2,465	2,626
Battery Waste	155	167	179	190	230	270
Waste from Electrical and Electronic Equipment (WEEE)	727	752	819	891	978	981
Waste Oils and Oily Sludge	157	154	151	148	146	143
Sewage and Industrial Sludge	9,773	9,911	10,057	10,212	10,350	10,550
Total	**208,496**	**210,125**	**226,545**	**235,223**	**245,693**	**268,142**
Population of Limerick and its Environs	76,176	76,916	77,657	78,397	79,137	80,447
Total Waste Generated per Capita	**2.7**	**2.7**	**2.9**	**3**	**3.1**	**3.3**

Table 4: Total Waste Generated in Limerick City and its Environs, 1992-1997 (Tonnes Per Annum) (Carey et al., 1996; Crowe et al., 2000; Meaney et al., 2003; Collins et al., 2004a; Collins et al., 2004b; Collins et al., 2005)

	1998	**1999**	**2000**	**2001**	**2002**
Municipal Waste	64,064	70,197	77,254	75,783	83,090
Industrial Waste	162,846	162,577	166,134	108,225	120,536
C & D Waste	23,966	26,655	29,344	32,030	35,624
Healthcare Waste	76	99	122	146	189
Packaging Waste	18,228	19,959	21,691	23,307	24,007
Scrap Metal Waste from End-of-Life Vehicles	1,235	1,736	2,119	1,561	1,303
Scrap Tyres	2,799	2,971	3,144	3,316	3,520
Battery Waste	350	390	447	431	522
Waste from Electrical and Electronic Equipment (WEEE)	1,061	1,249	1,325	1,478	1,692
Waste Oils and Oily Sludge	140	137	135	129	127
Sewage and Industrial Sludge	10,735	10,919	11,113	11,288	11,503
Total	**285,500**	**296,891**	**312,826**	**257,694**	**282,112**
Population of Limerick and its Environs	81,757	83,067	84,377	85,867	86,998
Total Waste Generated per Capita	**3.5**	**3.6**	**3.7**	**3**	**3.2**

Table 5: Total Waste Generated in Limerick City and its Environs, 1998-2003 (Tonnes Per Annum) (Carey et al., 1996; Crowe et al., 2000; Meaney et al., 2003; Collins et al., 2004a; Collins et al., 2004b; Collins et al., 2005)

	1996	**2002**
Direct Material Input (DMI)	1,856,231	2,468,311
Hidden Flows Associated with Domestic Production	180,151	233,918
Total Material Input (TMI)	2,036,382	2,702,229
Population of Limerick and its Environs	79,137	86,998
TMI Per Capita	**26**	**31**
Hidden Flows Associated with Imports	677,713	719,912
Total Material Requirement (TMR)	2,714,095	3,422,141
TMR Per Capita	**34**	**39**

Table 6: Total Material Input (TMI) and Total Material Requirement (TMR) for Limerick City and its Environs, 1996 and 2002 (Tonnes per Annum)

	1992	1993	1994	1995	1996	1997
Total Waste Generated	208,496	210,125	226,545	235,223	245,693	268,142
Total Air Emissions	700,296	694,285	722,231	740,864	770,785	821,069
Domestic Processed Output (DPO)	908,792	904,410	948,776	976,087	1,016,478	1,089,211
Population	76,176	76,916	77,657	78,397	79,137	80,447
DPO Per Capita	11.9	11.8	12.2	12.5	12.8	13.5
National Physical Exports	10,347,793	9,966,296	10,085,614	10,790,051	11,269,195	11,411,458
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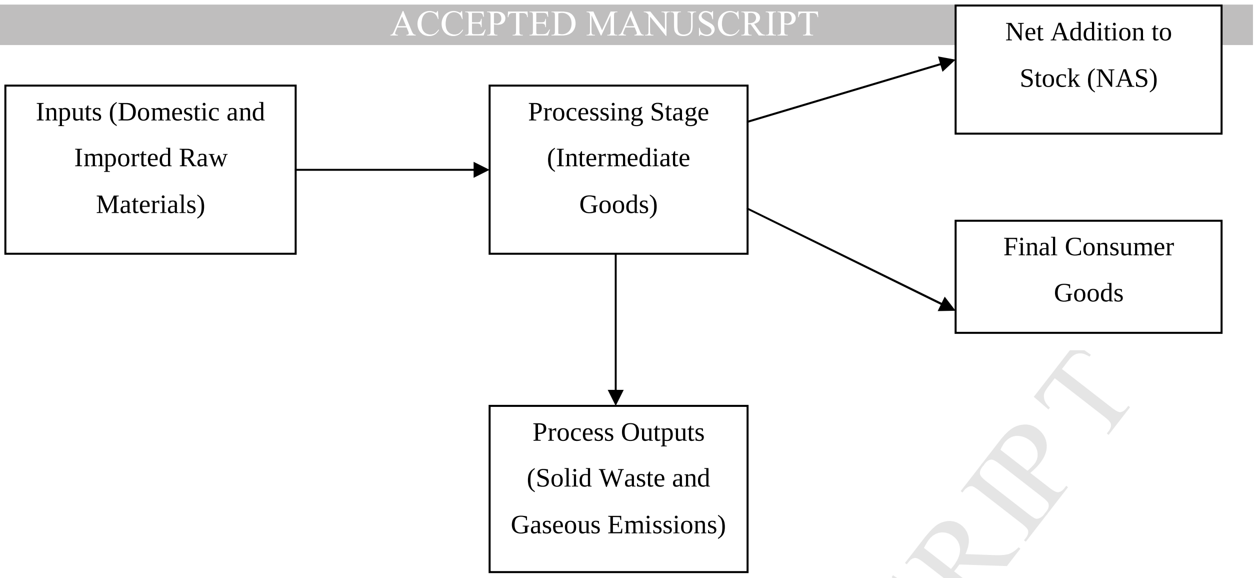

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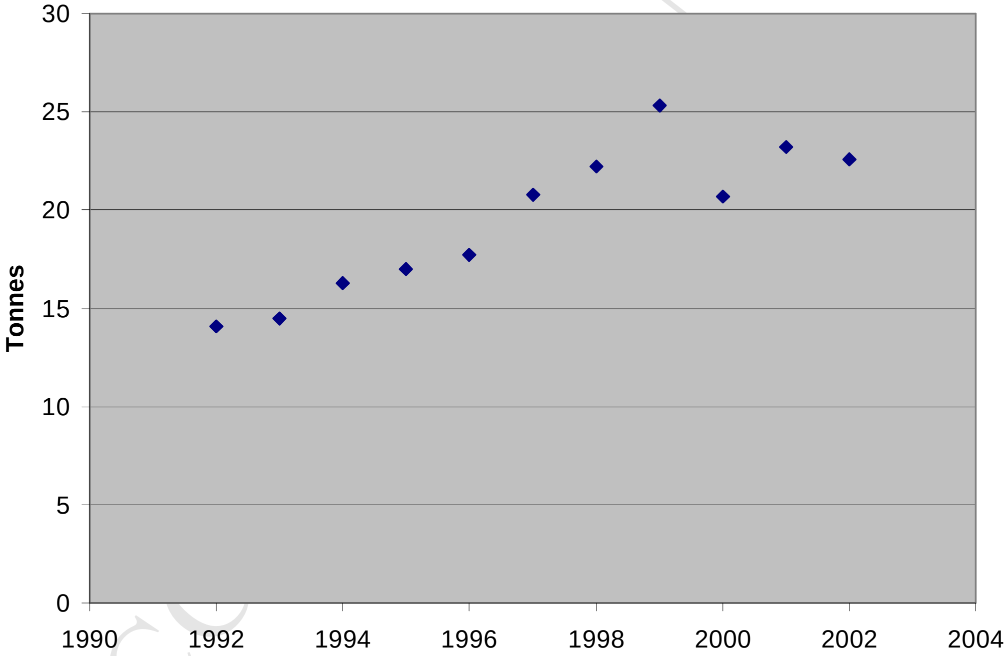

Figure 2: DMC per capita of Limerick residents, 1992-2002 (Tonnes)

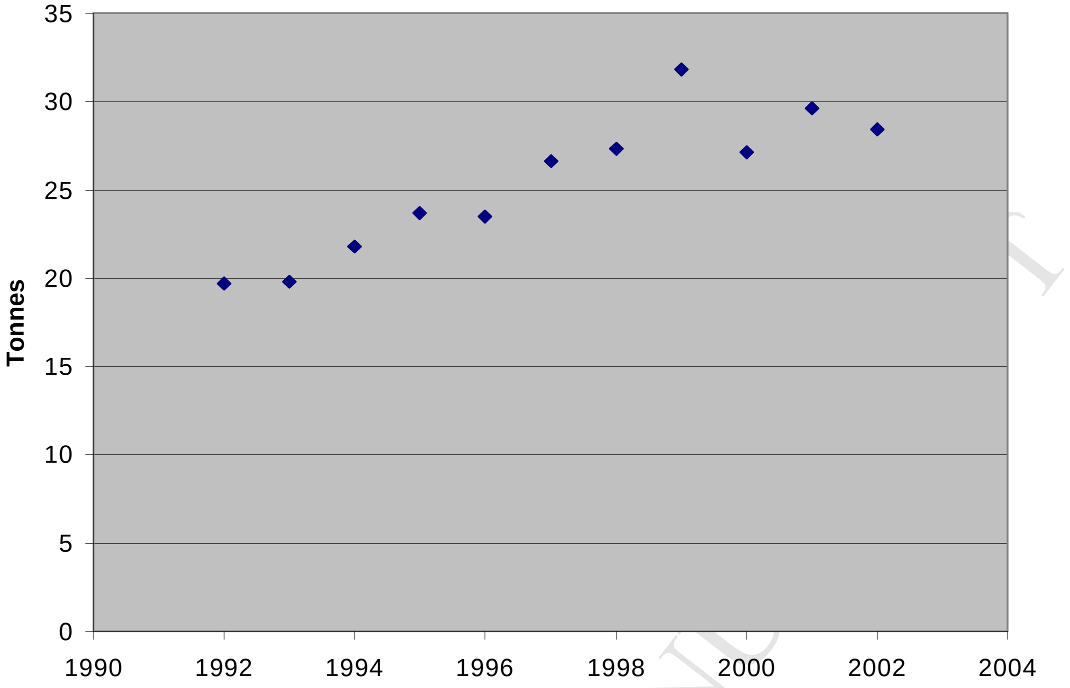

Figure 3: DMI per capita of Limerick residents, 1992-2002 (Tonnes)

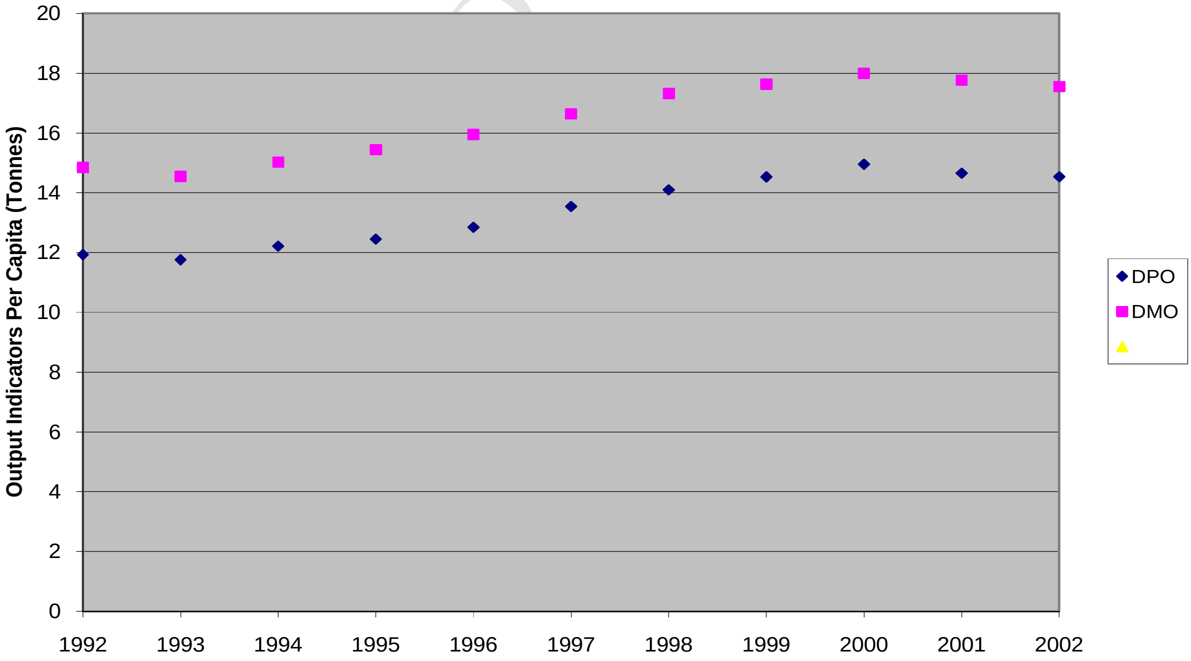

Figure 4: DPO and DMO Per Capita of Limerick Residents 1992-2002 (Tonnes)