Theoretical Appraisal of Sustainability Metrics and Empirical Application to an Irish City-region to Assess Current and Future Sustainability

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Abstract

The purpose of this paper is to appraise a myriad of sustainability measurement methodologies, using a number of criteria, including strengths and weaknesses, data requirements, outputs and applicability at various spatial and temporal scales. The main criterion was the ability to measure and monitor sustainability of a sub-national settlement and to facilitate scenario building in order to assess the likelihood of current policy measures achieving sustainability in the selected city-region. The methods that were selected and empirically applied to the case-study, i.e. the Limerick city-region are urban metabolism, carbon and ecological footprinting and trend to target assessment. The aim of the research is to develop the optimal policy mix, which will help guide the city-region along a more sustainable trajectory and highlight trends in critical indicators and sectors, commonalities, feedback loops and leverage points in the policy-making process.

Keywords: Sustainability appraisal, metabolism, footprinting, integrated assessment

Introduction

Sustainability measurement and modelling is the empirical expression of the sustainable development paradigm, which involves the holistic integration of theories of systems ecology (Odum 1972; 1994), self-organisation and resilience (Kay & Schneider, 1994), the entropy law and emergy analysis (Georgescu-Roegen, 1971; Brown & Herendeen, 1996; Brown & Ulgiati, 1999), input-output analysis and material balances (Ayres & Kneese, 1969; Leontief & Ford, 1970), biophysical (Cleveland, 1987; Cleveland & Ruth, 1997) and ecological economics (Costanza, 1991; Costanza & Daly, 1992) and natural capital accounting (Hartwick, 1977; Wackernagel et al., 1999).

Sustainability has been defined variously as the "capacity to create, test, and maintain adaptive capability" (Holling, 1973), the resilience of socio-ecological systems (Carpenter *et al*., 2001) or "living within the regenerative capacity of the biosphere, whilst maintaining natural capital" (Wackernagel *et al*., 2002). It has been variously appended to describe states of natural, financial, manufactured, cultural and social capital. Sustainable development, however, is essentially more of a directional trajectory or an 'ethical guiding principle' along an aspirational path of human, social and economic development (Reid, 1995, p16). It may be visualised as a fully integrated, holistic triptych or 'prism of sustainability', which involves the balanced co-evolution of environmental, economic and social cohesion concerns (Spangenberg, 2001, p184).

It is increasingly being recognised that urban settlements have a role to play in achieving sustainability with the United Nations, European Community and the World Bank now having sustainable cities programmes, including the International Council for Local Environmental Initiatives (ICLEI) and the European Common Indicators Project (Ambiente Italia, 2003, p7). Nijkamp & Opschoor (1995) have defined a 'sustainable city' as a city-region in which negative effects stemming from the interaction of the three different environments, i.e. physical, social and economic are kept within certain threshold conditions associated with the urban carrying capacity (Camagni *et al*., 1998, p106).

City-regions have been described as "dynamic and complex ecosystems" (Tjallingii, 1993, p7), which are intensive and specialised hubs of activity, mobilizing resources, goods, services and information (Ravetz, 2000, pp35-36). They concentrate human population and resource consumption, which results in a variety of ecological impacts that would not occur, or would be less severe, with a more dispersed settlement pattern (Rees & Wackernagel, 1996, p242). City-regions appropriate the ecological output and life support functions of the global hinterland through commercial trade and natural biogeochemical cycles (Rees & Wackernagel, 1996, p236). Thus, in complex systems theory, they are regarded as "dissipative structures", as they continuously degrade and dissipate available energy and matter, in adherence to the Second Law of Thermodynamics or Entropy Law, by transforming low entropy, high-quality materials into high entropy residual wastes in a linear processing system (Rees & Wackernagel, 1996, p37). However, Alberti & Susskind argue that the sheer concentration of population and consumption gives cities enormous leverage in the quest for global sustainability due to lower costs per capita, higher population density and economies of scale (Alberti & Susskind, 1996, p213).

Methodologies

Methodologies for measuring sustainability range from sets of simple socio-economic and environmental quality or state indicators to complex, holistic integrated models with feedback loops and inter-linkages. The methodologies considered include:

1. Community sustainability indicators and indicator sets, i.e. Pressure-State-Response (PSR) Framework

2. Macro-economic and socio-political indicators, including environmentally-adjusted net national product (EANNP), satellite environmental-economic accounting (SEEA), genuine savings approach, measure of economic welfare (MEW), index of sustainable economic welfare (ISEW) and genuine progress indicator (GPI)

3. Environmental-economic indicators, including material flow accounting (MFA), biophysical accounting, ecological footprint analysis (EFA) and environmental space

4. Integrated assessment (IA) frameworks, e.g. Integrated Sustainable Cities Assessment Method (ISCAM), multi-criteria decision analysis (MCDA), decision support systems and analytical hierarchy process (AHP)
5. Other modelling approaches, including input-output and econometric modelling of policies, computable general equilibrium (CGE) modelling and systems dynamics models, e.g. Limits to Growth, POLESTAR, QUEST, Threshold 21

The strengths, weaknesses, potential applications, data inputs, outputs and applicability at various spatial scales of these methodologies were compared and it was decided that material flow accounting (MFA), ecological footprinting (EF) and an integrated assessment (IA) method were the most suitable methods for measuring and monitoring sustainability at a sub-national level as data are available for these methods to be implemented and they can be used for sectoral analysis, which allows for corroboration and analysis of individual results and indicates optimal pathways for defensive expenditure, policy formulation and objective-focussing. Other indicators including welfare indicators and socio-political measures are more operational at a macro-level whereas modelling approaches such as econometric modelling and CGE modelling are more useful for estimating the macro-economic effects of certain fiscal policies.

Material Flow Accounting (MFA) and Urban Metabolism

MFA aims to quantify the flow of resources, in terms of mass, within a defined geographical area or industry sector over a set period of time by means of material input, output and consumption indicators, including Direct Material Input (DMI), Domestic Material Consumption (DMC), Total Material Requirement (TMR) and Domestic Processed Output (DPO) (Hinterberger, 2003, p7; Krausmann *et al*., 2004, p30). The various indicators used in MFA differ with respect to what stage of the material life cycle they measure and to what extent they include ‘hidden flows’ or ‘ecological rucksacks’, i.e. ancillary and excavated materials extracted from the natural environment in the economic process (Krausmann *et al*., 2004, p30; 217). The strengths, applications and weaknesses of MFA are given in Appendices – Table 1. In order to complete a material flow analysis for the study area and assess urban metabolic inefficiency, it was necessary to quantify:

- Material production for Standard International Trade Classification (SITC) Divisions 00-43, including agriculture and natural textiles, forestry and wood products, fishing and aquaculture, coal, lignite and peat extraction, oil and gas extraction, construction materials and other crude minerals and mining and quarrying of metalliferous ores
- Material imports and exports
- Material consumption within the study area
- Manufactured good production and trade
- Municipal, industrial and priority waste production
- Methods of waste management and treatment, i.e. rates of disposal and recycling

- Energy balances and emissions

The concept of urban metabolism, which is closely related to MFA, was first propagated by Wolman (1965) and involves exploring the interactions among resource flows, urban transformation processes, waste streams and quality of life (Newman, 1999, pp220-221). Urban metabolism models can be used to show efficiency of production and consumption and part of this research involved developing a novel material flow indicator called 'metabolic inefficiency', which links final waste disposal to final product consumption at a consumer level.

Industrial sectors and economic activities for which production and trade data were collated include:

1. Food and agriculture
2. Textiles and leather products
3. Pulp and paper products
4. Chemicals, rubber and plastic products
5. Basic metals, fabricated metal products and machinery and equipment
6. Electrical and optical equipment
7. Transport equipment
8. Wood, wood products and furniture
9. Other non-metallic mineral products
10. Manufacturing not elsewhere classified

Production data were collated from the Irish Central Statistics Office (CSO) PRODCOM publications, which report the value of product sales in sectors, according to standard industrial classification. The weight of 1 produced tonne of manufactured goods in each sector was, thus, estimated by dividing the value of exports by weight of exports. The weight of product sales was then estimated by dividing the value of product sales by the value of 1 exported tonne for that year in each industrial sector.

Import and export data of intermediate and final manufactured goods as well as raw materials and fibres were obtained for SITC Divisions 00-99 from the Trade Division of the CSO in order to determine net addition to or reduction from stock. Thus, total national consumption of manufactured goods in 1996 and 2002 was estimated as well as tonnes per capita, by adding national production and net addition to stock, i.e. the trade balance of imports minus exports. The per capita figures for consumption were adjusted by using ratios of weekly expenditure by Limerick residents on household items, which were taken from the National Household Budget Survey 1999-2000 micro-data, compared with weekly expenditure by an average Irish household and then multiplied by the population of Limerick city and its environs.

Material composition of household waste in the Limerick urban district was taken from the Irish Environmental Protection Agency (EPA) *National Waste Database Reports* and was multiplied by total household waste collected in Limerick city and its environs in order to estimate household waste collected by material type. The material recycling rates in the household waste stream in the Limerick urban district were used to estimate rate of disposal and, thus, the quantity of material household waste disposed of by various means.

Material composition of commercial waste in Ireland was also taken from the *National Waste Database Reports* and was multiplied by total commercial waste collected in order to estimate commercial waste collected by material type. The national material recovery rates in the municipal waste stream were used to estimate rate of disposal and, thus, the quantity of material commercial waste disposed of by various means.

Total waste generated in different industries and total reported industrial waste in Ireland was used to estimate the proportion of industrial waste generated in various economic sectors. National disposal rates by various means, including landfilling, incineration were used. This material composition approach was also used for packaging waste.

Ecological Footprinting

The ecological footprint (EF) is a land-based measure of the population's demands on natural capital and is defined as the total area of productive land and water required to produce all the resources consumed and to assimilate all the wastes produced by a defined population, regardless of where that land is located (Rees & Wackernagel, 1996, pp228-229). Its strengths, applications and weaknesses are given in Appendices – Table 2.

The ecological footprint analysis (EFA) involved collecting data for a range of activity components, including food, materials and waste, direct residential and commercial services energy consumption, passenger transport, freight transport, , construction and land use in order to estimate both direct and indirect impacts. The impacts of these activities are then converted into the hypothetical land area required to supply the end use services. The land footprint is the sum of arable and pasture land required to supply agricultural products, estimated by dividing average annual consumption of that item by its average annual productivity or yield, the exclusive economic zone (EEZ) of sea area harvested for fish consumption, forested land required for wood and paper production, and physical land appropriation for road infrastructure, residential housing, industrial zoned land and commercial and public services.

The carbon footprint was also calculated by estimating the carbon emissions from the energy embodied in the production and transport of food, manufactured product and construction material to final consumers using net calorific value (NCV) and carbon emission factors. The embodied energy associated with the production of a consumption item is calculated through a hybrid method of process, life cycle and input-output analysis and average embodied energy values were used. The emission factors used were collated from the Irish Environmental Protection Agency (EPA), International Energy Agency (IEA) and Sustainable Energy Ireland (SEI). Direct carbon emissions were also estimated from energy and electricity consumption in the residential, commercial and public services and transport sectors. Carbon emissions were then converted into a theoretical land area required to sequester carbon produced both domestically and emissions associated with imports. The aggregate ecological footprint was then estimated as the sum of the land and carbon footprints for each consumption item and sector. A hybrid compound-component approach was used in which national production, trade and energy consumption data are being used along with settlement-specific data.

Integrated Assessment (IA) and Trend to Target Assessment

Integrated assessment (IA) may be defined as "the interdisciplinary process of combining, interpreting and communicating knowledge pieces from diverse scientific disciplines in such a way that insights are made available to decision makers"(Rotmans *et al*., 2000, p266). The Integrated Sustainable Cities Assessment Method (ISCAM) is a scenario accounting system for the total environmental metabolism of a settlement, city or region (Centre for Urban and Regional Ecology (CURE), 2000, p2) and allows for strategic assessment and sustainability appraisal of policies and programmes, where indeterminate and cumulative effects can be placed in a whole-system context of trends, projections, goals and targets (Ravetz, 2000, p31). The ISCAM aims to assess sustainability in a city-region in dynamic evolution by looking at policy gaps between current trends and selected targets, for each aspect or indicator of the system (Ravetz, 2000, p34).

It seeks to project future trajectories of selected indicators to 2020 using a simple linear progression and Business as Usual (BAU) assumptions of current indicator trends and existing policies. This time frame was used as it represents the typical time frame of a strategic plan, policy or programme. The intrinsic statistical error is minimised by selecting indicators for which much reliable and consistent data were available, thus allowing for the plotting of data points at close time intervals and the prediction of future trends within a reasonable time scale. In terms of extrapolation, linear or deterministic trends are the most mathematically robust and for this reason, a number of common sustainability indicators were not selected. Policy targets were selected from the current policies being disseminated from international commitments and voluntary targets, European Union (EU) directives and burden-sharing agreements, national policies, plans and programmes and regional and local development plans.

A component approach was also used to facilitate comparison with material flow, metabolism and ecological footprint methods. The individual indicators are then aggregated to give sectoral and overall indices and these are used as sustainability metrics for comparative purposes (Ravetz, 2000, p53). Its strengths, applications and weaknesses are given in Appendices – Table 3. It is hoped that common trends will be revealed by the different methods and highlight the need for objective-focussing in certain sectors. Finally, the current and proposed policy mix is being assessed with regards to its likelihood of achieving sustainability by considering trend divergence or convergence and, if necessary, alternative policies will be developed and their impact assessed in order to create the optimal policy mix.

Results/Calculations

Urban Metabolism and Metabolic Inefficiency

Food consumption by Limerick residents was estimated from national average food consumption per capita, obtained from the Irish Food Board (Bord Bia) by personal consumption, and was adjusted using an expenditure proxy, available from the National Household Budget Survey. Thus, it was estimated that 40,271.2 tonnes of food were consumed by Limerick residents in 1996 while 48,884.9 tonnes were consumed in 2002.

The estimated household waste collected in the Limerick administrative area in 1996 was 31,401.5 tonnes and in 2002 was 29,600.8 tonnes. The composition of household waste in the Limerick urban district in 1998 consisted of 34.64% organics (Crowe *et al*., 2000, pp149-157). Therefore, it was assumed that 10,877.5 tonnes of household organic waste were collected in 1996. However, 3.1% of this was biodegradable waste from gardens and parks. Hence, 10,540.3 tonnes of household food waste were collected in 1996. The recycling rate for putrescibles/organics in the household waste stream in 1998 was 1.5% (Crowe *et al*., 2000, p31) and, therefore, 98.5% was landfilled, i.e. 10,382.2 tonnes. The composition of household waste in the Limerick Urban District in 2002 consisted of 32.2% organics (Collins, 2004a, p7), i.e. 9,531.5 tonnes and it was assumed that 31.2% of household waste collected in the Limerick region in 2002 is food waste, i.e. 9,235.45 tonnes. The recycling rate for putrescibles/organics in the household waste stream in 2002 was 7.4% (Collins *et al*., 2004a, p8) and, therefore, 92.6% was landfilled, i.e. 8,552 tonnes.

This method was repeated for commercial and industrial waste and it was estimated that total household, commercial and industrial food waste disposed of by various means in 1996 was 16,698.6 tonnes and metabolic inefficiency was 41.5%. The total household, commercial and industrial food waste disposed of in 2002 was found to be 20,969.2 tonnes and, thus, metabolic inefficiency was estimated to be 42.9%.

The same procedure was used for all sectors and it was found that total household, commercial, industrial, packaging and other priority waste, except for solid agricultural waste, disposed of by various means in Limerick in 1996 was 106,432.3 tonnes. Consumption of durable and non-durable products and construction materials was 827,010.5 tonnes and metabolic inefficiency was 12.87%. Total household, commercial, industrial, packaging and other priority waste disposed of by various means in 2002 was 125,733.4 tonnes. Consumption of durable and non-durable products and construction materials was 1,352,626.3 tonnes and metabolic inefficiency was 9.3%. Figures 1 & 2 show the sectoral metabolic inefficiencies for materials and waste for 1996 and 2002. Figure 3 shows the comparative difference in sectoral and overall metabolic inefficiency between 1996 and 2002 for industrial sectors. Figures 4 & 5 show the sectoral metabolic inefficiencies for energy and emissions for 1996 and 2002. Figure 6 shows the comparative difference in sectoral and overall metabolic inefficiency between 1996 and 2002 for energy sectors.

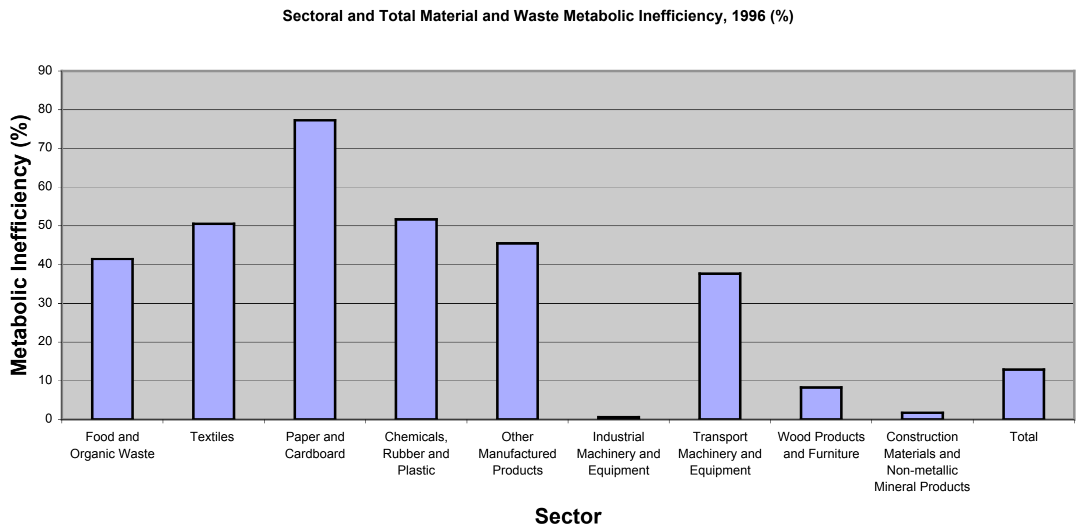

Figure 1: Sectoral and Total Material and Waste Metabolic Inefficiency, 1996 (%)

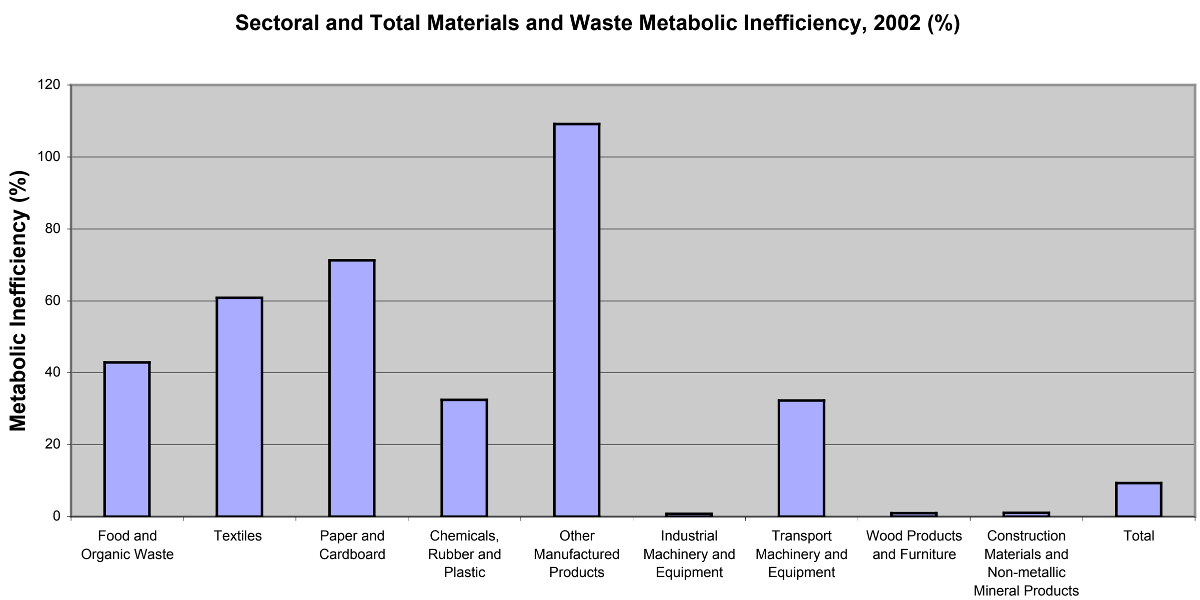

Figure 2: Sectoral and Total Material and Waste Metabolic Inefficiency, 2002 (%)

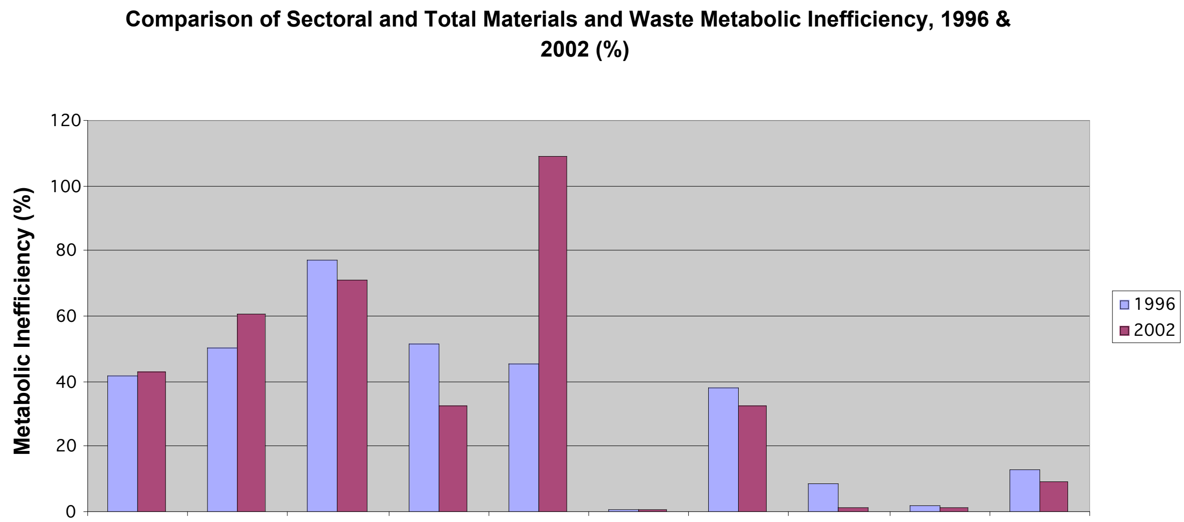

Figure 3: Comparison of Sectoral and Total Material and Waste Metabolic Inefficiency, 1996 & 2002 (%)

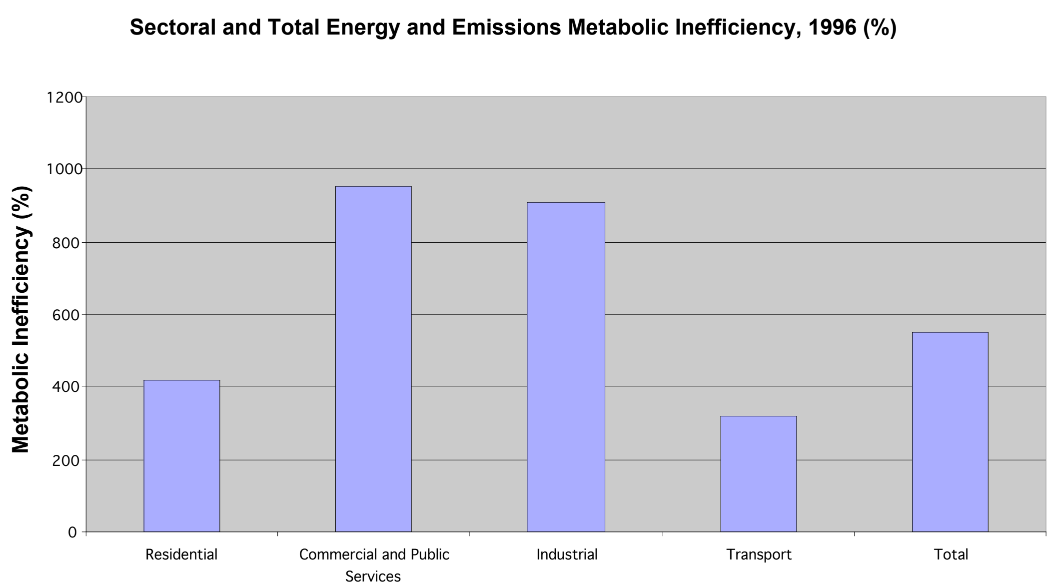

Figure 4: Sectoral and Total Energy and Emissions Metabolic Inefficiency, 1996 (%)

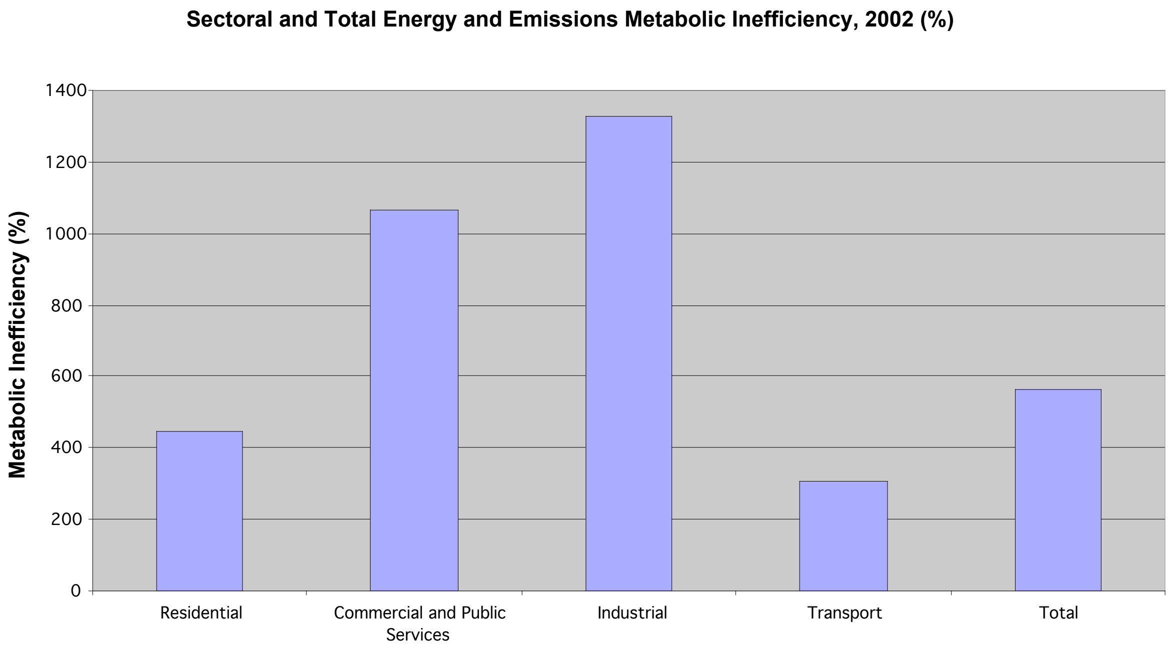

Figure 5: Sectoral and Total Energy and Emissions Metabolic Inefficiency, 2002 (%)

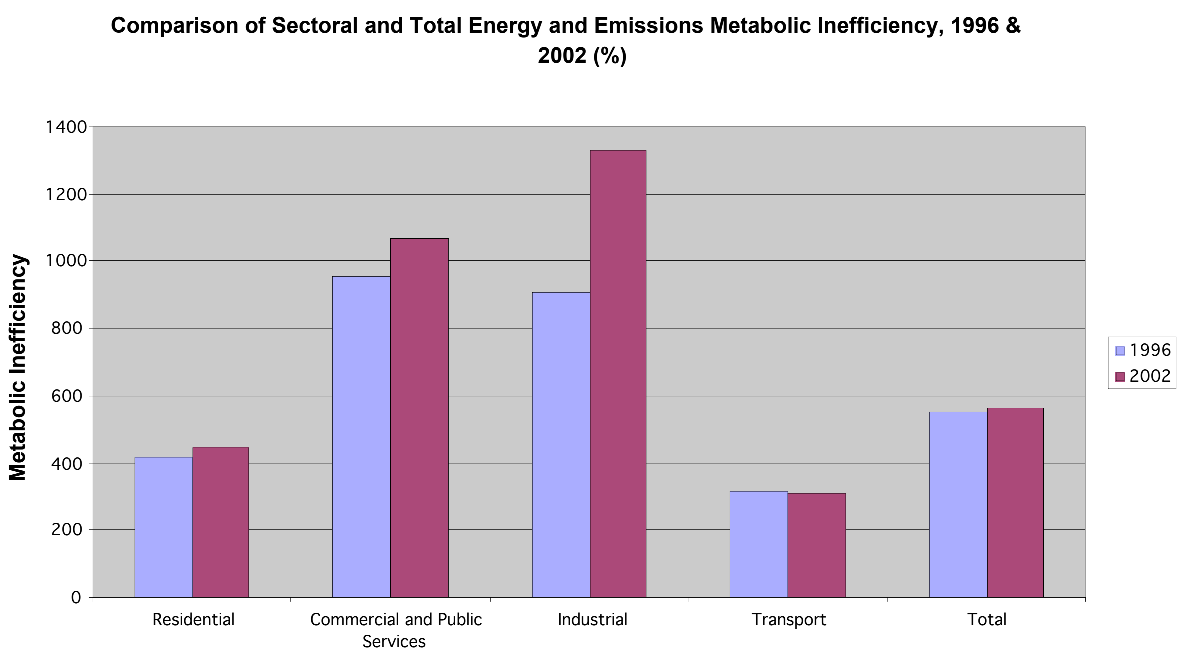

Figure 6: Comparison of Sectoral and Total Energy and Emissions Metabolic Inefficiency, 1996 & 2002 (%)

Carbon Footprinting

The total embodied energy of food and agricultural product imports to Ireland was 17,794.9MJ per capita Irish resident in 1996 and 19,372.8MJ per capita Irish resident in 2002, estimated from average embodied energy values (in MJ per kilogram) and import data.Limerick resident per capita consumption was estimated by comparing average weekly household expenditure in Limerick with average national weekly household expenditure using National Household Budget Survey 1999-2000 micro-data and an expenditure ratio of 0.8756 was used. Therefore, embodied energy of food and agricultural product imports per Limerick resident was 15,581.21MJ in 1996 and 16,962.8MJ in 2002. The percentage value of imports of food products per major trading partner with Ireland was estimated and average embodied energy per capita Limerick resident apportioned accordingly.

The fuel mix associated with industrial production in Ireland and imports of food items from its main trading partners for solid fuels, oil and petroleum products, natural gases and waste gases and biomass for 1996 and 2002 were obtained from IEA published statistics and all fuel data were converted to terajoules (TJ) by using net calorific value (NCV) conversion factors. The renewable percentages of net electricity production for 1996 and 2002 for Ireland and major trading partners were used as a deduction from the carbon emissions from electricity used in industry and manufacturing as it was assumed that the renewable sources of electricity produced no carbon emissions. Carbon emission factors were then used to estimate emissions associated with production and imports.

Table 4 shows the carbon emissions per capita associated with embodied energy of food imports for 1996 and 2002 per major trading partner. The ratio of (production – exports) to production in 1996 is 0.74238. The ratio of (production – exports) to production in 2002 is 0.72795. Table 5 shows the carbon emissions per capita Limerick resident associated with consumption of food items produced domestically in Ireland. Thus, total carbon emissions per capita Limerick resident associated with consumption of food in 1996 was 0.434 tonne, with imports accounting for 75.326%. The, total carbon emissions associated with consumption of food in 2002 was 0.476 tonne, with imports accounting for 78.08%. Carbon emissions per capita associated with food consumption increased by 9.68% between 1996 and 2002.

The carbon emissions were calculated for each sector and converted to land footprints using domestic and international sequestration rates. Figure 7 shows the sectoral carbon production for 1996 and 2002. Figure 8 shows carbon footprints after emissions were converted to global hectares per capita using sequestration rates and equivalence factors for energy land type.

Trend to Target Assessment

Trend to target assessment has been carried out for dematerialization, solid waste generation and management, sectoral climate change policy targets and renewable energy and electricity. The recycling rate for the household waste stream in Ireland increased from 3.2% in 1998 to 19.5% in 2004, i.e. a rate of increase of 2.72% per annum. The policy target used was diversion of 50% of overall household waste away from landfill

(Department of the Environment and Local Government (DoELG), 1998, pp6-7; RPS, 2005, pxii). As there is no incineration of landfill in the study period 1998-2003, it was assumed that all waste not disposed of via landfill was recovered and recycled. The Trend to Target Index was calculated to be 0.645.

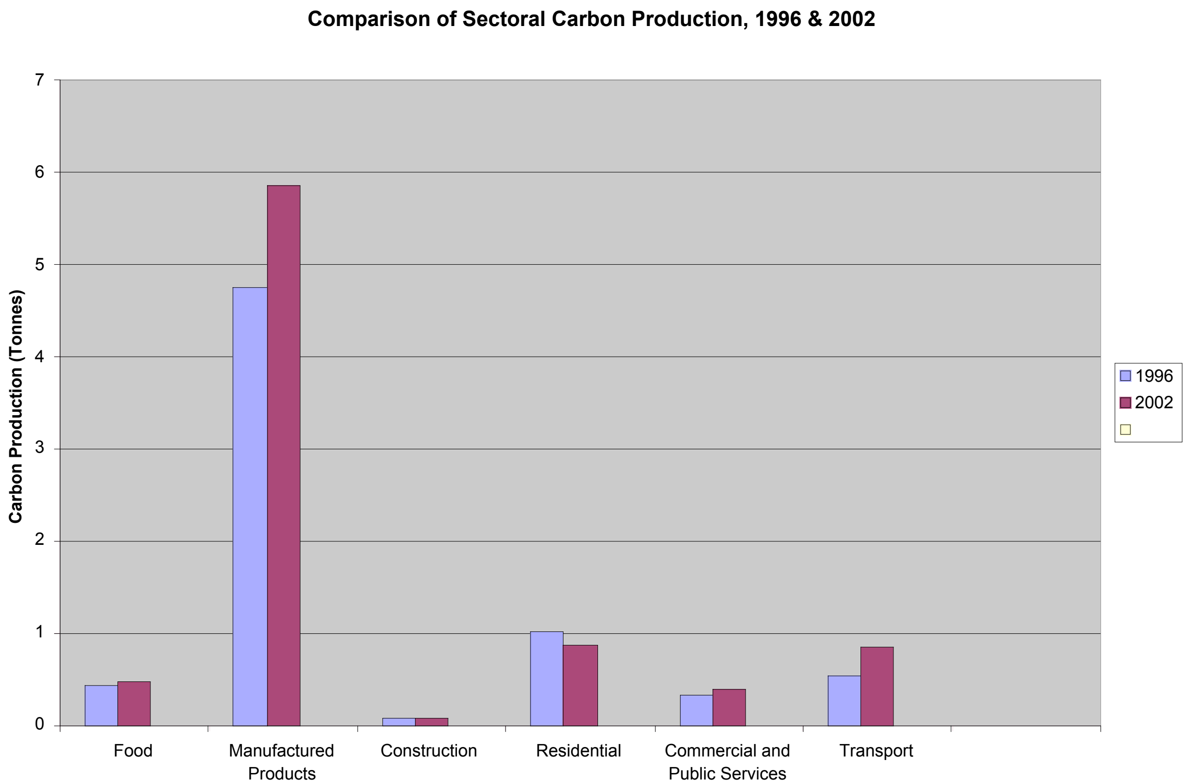

Figure 7: Comparison of Sectoral Carbon Production, 1996 & 2002 (Tonnes)

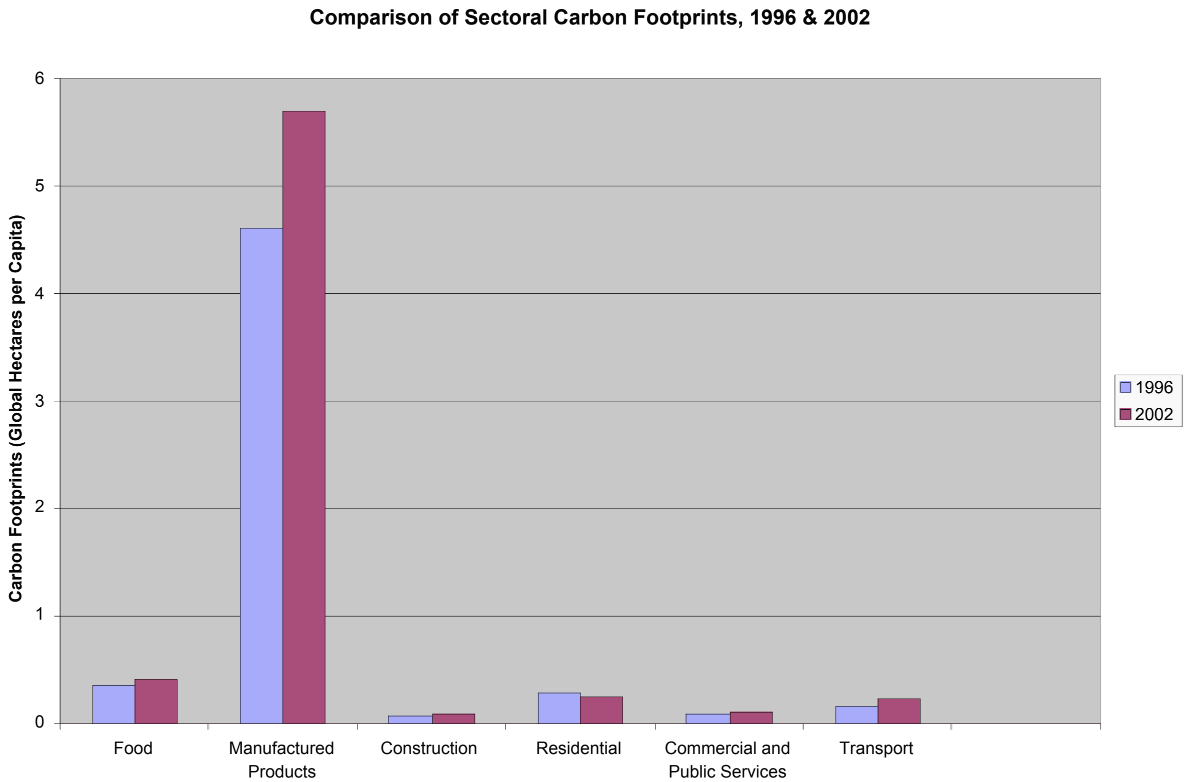

Figure 8: Comparison of Sectoral Carbon Footprints, 1996 & 2002 (Global Hectares per Capita)

The quantity of household waste collected in Limerick city in 2003 was 29,244 tonnes, estimated from local authority National Waste Database (NWD) returns, while 1,704 tonnes were uncollected (RPS, 2005, p31). Dry recyclables collected from kerbside were 6,067 tonnes (RPS, 2005, p32). Other quantities collected for recycling include 527 tonnes from bring banks and 317 tonnes from recycling centres, giving total recycled quantity of 6,912 tonnes. The recycling rate for Limerick city was, therefore, estimated to be 22% in 2003 (RPS, 2003, p35). The overall national recycling rate for 2003 was 13.1%.

The amount of household waste collected in 2004 was 22,265 tonnes and 10,745 tonnes of non-household municipal waste and 3,100 tonnes of litter and street sweepings were also collected in 2004 by private contractors (Data available from Limerick city council, by direct personal communication). Total household recyclables collected were 3,020 tonnes, including 2,854 tonnes of mixed dry recyclables and 166 tonnes of food and garden green waste, indicating a recycling rate of 13.56%. Provisional waste data for the largest waste contractor in the area, available by direct personal communication with the Limerick city council, indicate that 11,212 tonnes were landfilled in 2005 and 3,592 tonnes were recycled, implying that a total of 14,804 tonnes were collected and a recycling rate of 24.26%.

The overall recycling target for the Limerick/Clare/Kerry region under the 2001 Plan was 41% across all waste streams by 2014 (RPS, 2005, p35). These targets were revised in the Draft Regional Waste Management Plan 2005-2010, which aims for 45% recycling, 41% energy recovery and 14% landfilling of total municipal waste and household waste arisings by 2013 (RPS, 2005, pxviii). The Trend to Target Index was calculated to be 2.07.

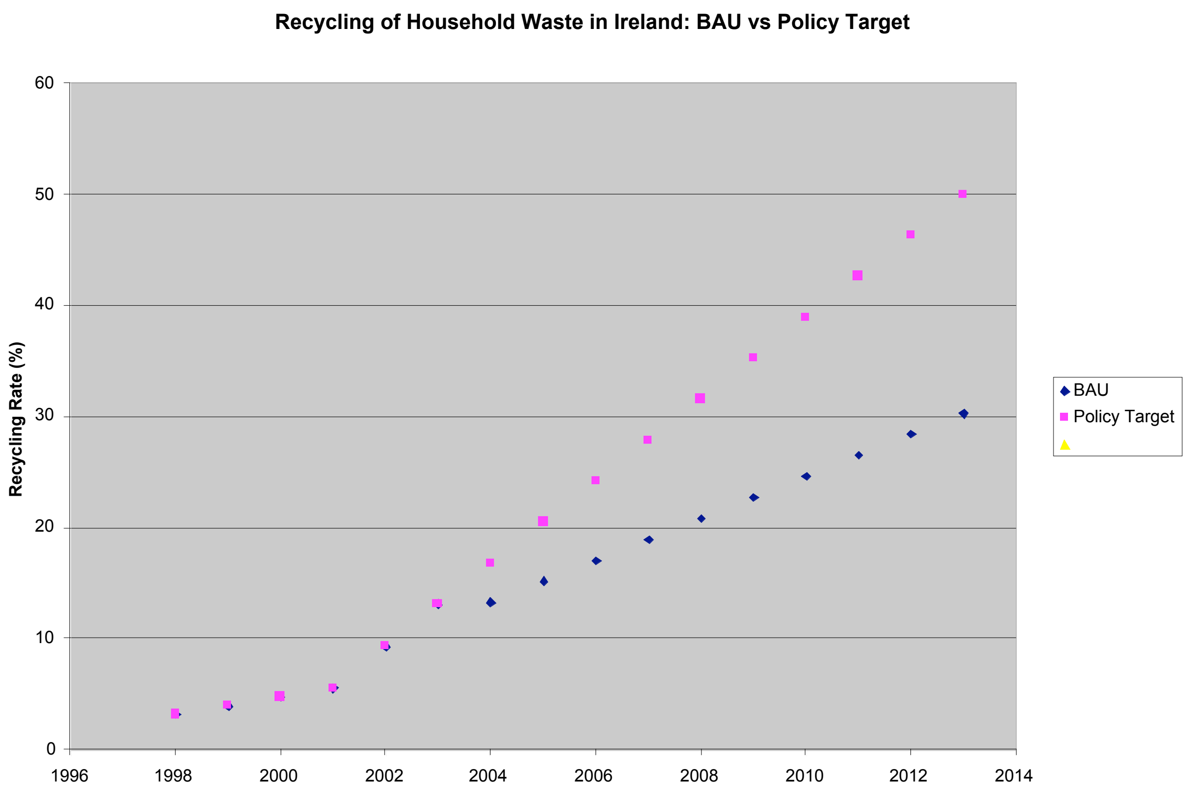

Figure 9: Recycling of Household Waste in Ireland

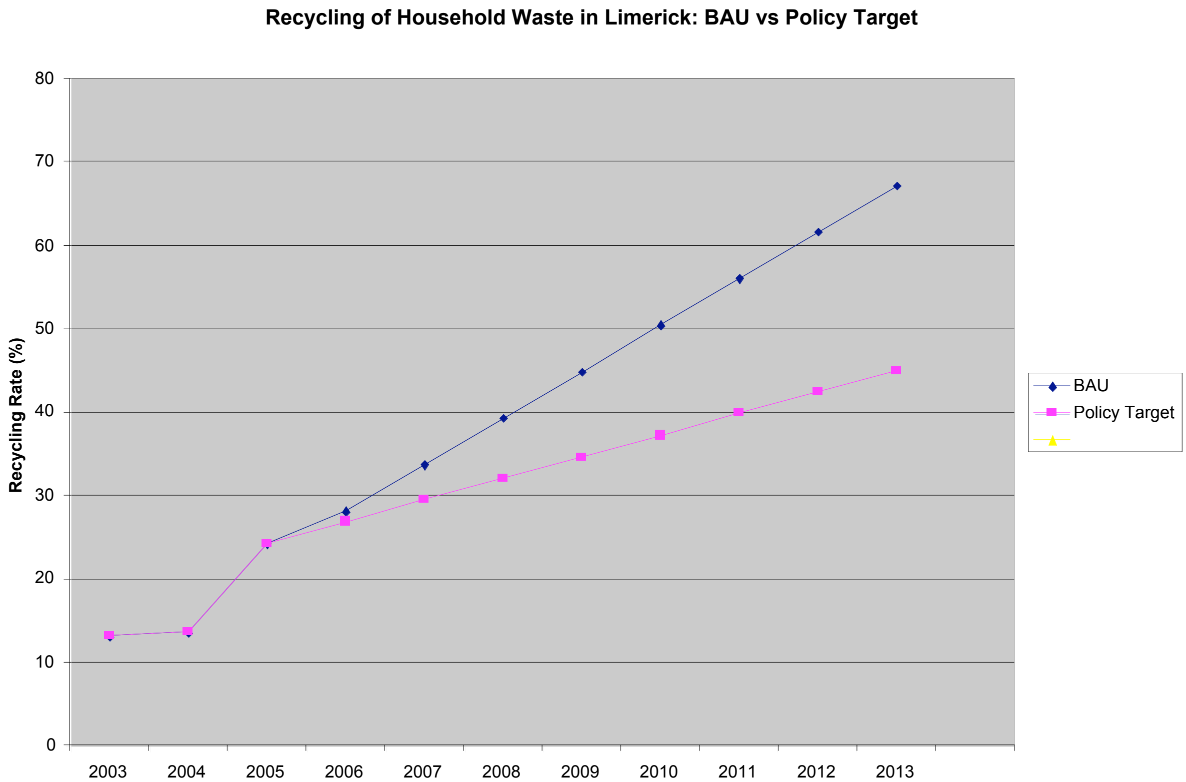

Figure 10: Recycling of Household Waste in Limerick

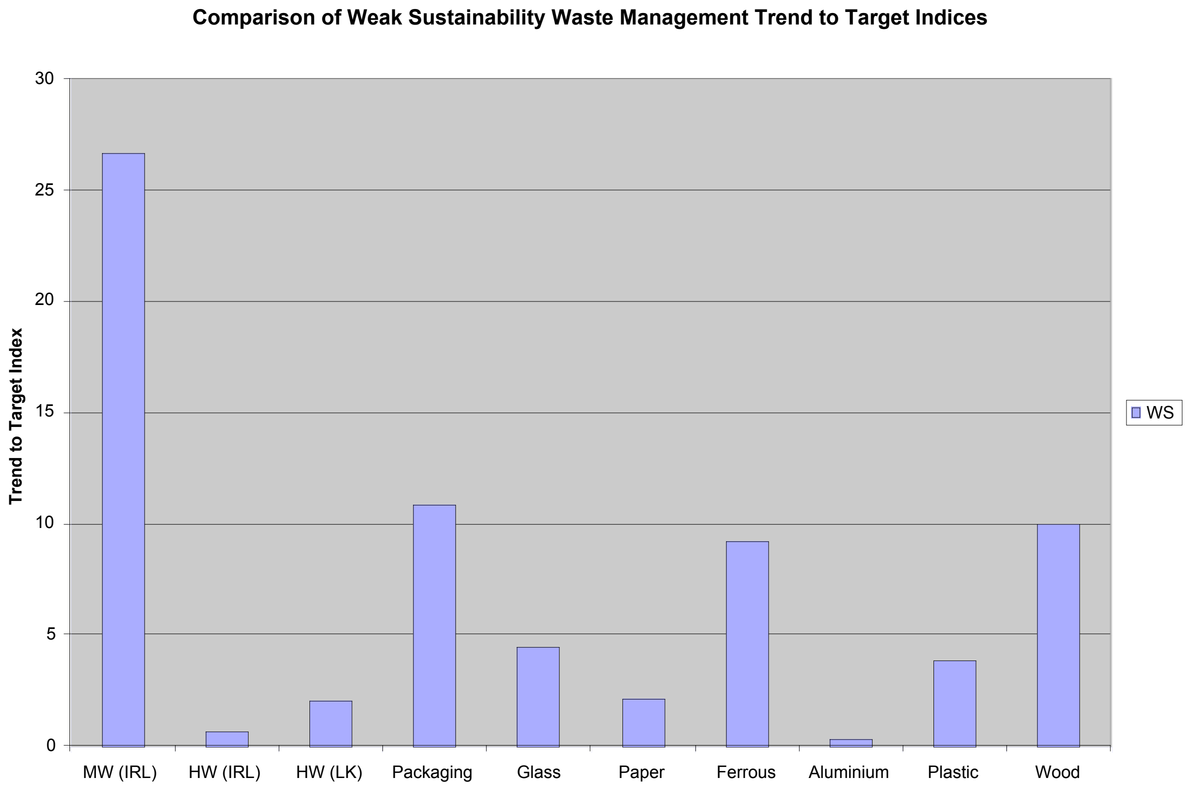

Figure 11: Waste Management Trend to Target Indices

Discussion and Conclusions

The urban metabolism and metabolic inefficiency methods, which were developed within this project, aim to integrate product consumption with environmental impact by comparing final waste disposal with household consumption in the city-region. The metabolic inefficiency indicator developed within this research is a novel empirical method for assessing urban sustainability and is useful in that highlights the most inefficient sectors in terms of waste production relative to useful consumption. For example, it was found that in 1996 paper and cardboard showed the highest metabolic inefficiency (77.3%), followed by chemicals, rubber and plastics (51.65%) and textiles (50.51%).

In 2002, the most unsustainable sectors in terms of materials and waste were other household manufactured products (109.1%), paper and cardboard (71.2%) and textiles (60.81%). Overall, the materials and waste metabolic inefficiency decreased from 12.87% in 1996 to 9.3% in 2002. In terms of energy and efficiency metabolism, commercial and public services showed the highest inefficiency in 1996 followed by industrial, while in 2002 the industrial sector showed the highest metabolic inefficiency. Total energy and emissions metabolic inefficiency increased from 549.5% in 1996 to 565.8% in 2002. The metabolic inefficiency indicator may be useful as a dematerialisation indicator or used concomitantly with waste intensity indicators, i.e. waste volume per capita or Gross Domestic Product (GDP) to see if inefficiency indicators correlate with the largest sectoral material flows in terms of volume or waste flows in higher 'value-added' industrial sectors.

Ecological footprint analysis (EFA) and the Integrated Sustainable Cities Assessment Method (ISCAM) were also applied across the same sectors as the metabolism method, in order to compare sectoral results and highlight commonalities. A modified footprint method was used, which focusses on the environmental implications and effects of international bilateral and multilateral trade and emphasizes the consumer responsibility principle associated with consumption and accounts for embodied energy in trade, which gives a more globalized perspective on greenhouse gas emissions than current reporting methodologies and highlights the need for distributional equity in current burden-sharing agreements.

The ISCAM method was originally developed and applied to the Greater Manchester area by Ravetz (2000) but has not been applied to other city-regions. It differs from the other methods in that it directly addresses socio-economic factors and is more inclusive of sustainability factors than biophysical methods and may be adapted and modified with stakeholder participation. The method developed within this research project was an attempt to operationalize ISCAM and propose a transparent white-box template, which may be modified and adapted by other local authorities. It is measured by estimating the distance to trend compared with the distance to target, i.e. (Current Value – BAU Value in 2020)/(Current Value – Policy Target). Small positive values indicate slow convergence towards target while large negative figures indicate deviation from target. Thus, the Trend to Target Index of 2.07 in the Limerick city-region compared with a national index of 0.645 shows that higher levels of recycling are being achieved in the urban study area, which supports the argument that sustainability is likely to be achieved in higher density urban settlements due to economies of scale.

The primary objective of this research is to assess if current policies are likely to achieve local sustainability and, as a result, three methodologies were empirically applied to the study area for validation purposes. The results were inconclusive in that different sectors showed varying levels of sustainability when tested using the different methodologies. Using the metabolism methodology and considering the inefficiency of both the solid waste and gaseous emission outputs, manufacturing industry followed by commercial and public services and residential show the highest levels of inefficiency. The 2002 ecological footprint analysis shows that manufactured products followed by transport, food and agriculture and residential energy use are the most unsustainable sectors. Using trend to target assessment and the current Irish *National Climate Change Strategy (NCCS)*, which was implemented in 2000, transport, followed by residential and manufacturing industries and construction showed large negative indices. It is interesting to note that the sectoral policy targets proposed in the 2000 NCCS are being revised in 2006 and it would be useful to calculate the sectoral trend to target indices using the revised indices.

The final stage of this research involves synthesizing elements of footprinting with trend to target assessment in order to estimate potential changes in ecological footprint components under a number of Business as Usual (BAU) and Sustainable Development (SD) scenarios. These scenarios are being developed using quantitative policy targets reflecting varying levels of sustainability. Thus, it might be possible to measure trend-to-target indices of ecological footprint components at a future date and measure divergent or convergent trends.

Scenarios will also be developed which consider:

- The effects of importing agricultural materials and crops from countries with higher arable land yields and productivities, thus reducing global fertilizer and pesticide use, i.e. agricultural intensity
- The effects of importing livestock products from countries with less intensive grazing regimes
- The effects of switching to a more organic or plant-based diet
- The effects of using recycled as opposed to virgin materials for production
- The use of sustainable and indigenous construction materials
- The effect of importing materials or products from countries closer to Ireland, thus, reducing the impacts of freight transport and civil aviation
- The effect of importing products from countries with a more renewables-based fuel mix
- The effects of afforestation or increasing notional carbon sequestration land in the vicinity of the city-region
- The effects of increasing car occupancy or reducing personal transport passenger-kilometres

Sustainability assessment may be described as a process by which the implications of an initiative on sustainability are evaluated, where the initiative can be a proposed or existing policy, plan, programme, project, piece of legislation, or a current practice or activity (Pope et al., 2004, p595). Assessment methods by default tend to look for what is tangible and measurable, while real-world phenomena and sustainability criteria are characterized by indeterminacy and multiplicity (Ravetz, 2000, p32). The need for sustainability assessment methods at all spatial and administrative levels is urgent as defensive expenditure and information awareness needs to be focused on the least sustainable sectors and priorities need to be stated. Current indicator methods often fail to:

1. Integrate the complex issues intrinsic in sustainable development in a holistic sense
2. Model complex dynamics of human, urban or natural systems
3. Represent bio-physical reality

4. Model the environmental implications of trade or consumption
5. Represent socio-economic or socio-political factors
6. Include citizen participation or stakeholder transparency

It is hoped that the methodology being developed within this research will be transferable and help to achieve sustainability by suggesting policy targets, which will help the city-region move along a more sustainable trajectory. By synthesizing ecological footprinting and trend to target assessment, sectoral data and results can be compared as a result of using harmonized and/or dimensionless units. Scenario building is also being used along with stakeholder involvement in order to assess the implications of the current Limerick city Development Plan, which was implemented in 2004, and the impacts in terms of footprinting as a result of local transport, energy and waste management policies. These scenarios are being developed as part of a sustainability appraisal of the development plans in the region, in accordance with the Strategic Environmental Assessment (SEA) Directive (2001/42/EC) and it is hoped that the results will allow for robust evidence-based policy-making.

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Appendices

Methodology	Strengths	Applications	Weaknesses
Material Flow Accounting	• Complete accounting of the biophysical dimensions of economic activities • Ability to monitor rebound effects and shifts of pollution between different environmental media • Focuses on "persistent" environmental problems related to scale rather than toxicity-related environmental problems • Data organization is compatible with System of National Accounts • Indicators on all levels of aggregation (micro, sectoral, macro, input, output, consumption, trade) • Provides macro indicators	• Integrated environmental-economic-social accounting • Calculation of resource productivities and role of technological and demand changes • Indicator of globalization, international trade and structural change as well as distribution of environmental burdens between developed and developing countries • Analyses of rebound effects by linking the macro and the micro perspective • Integrated sustainability modelling • Derivation of indicators for resource productivity and eco-efficiency • Provision of indicators for the material intensity of lifestyles • Permit analytical uses, including estimation of material flows and land use induced by imports and exports as well as decomposition analyses separating technological, structural and final demand changes	• Aggregated indicators provide no information on material substitution potential • Weak links between MFA indicators and environmental impacts • No weighting of material flows and no consideration of qualitative aspects • Link to the actors responsible for the activation of material flows is not established and, therefore, it is not clear which groups of society should contribute to a strategy of dematerialisation • Economy as a black-box, i.e. no separation between material inputs for production versus consumption • MFA studies in most cases focus on methodological issues and the presentation of material balances and aggregated indicators and do not reflect the policy-related uses of results

Table 1: Strengths, applications and weaknesses of Material Flow Accounting (Hinterberger et al., 1997, p11; Hinterberger et al., 2003, pp11-12; Giljum & Hinterberger, 2004)

Methodology	Strengths	Applications	Weaknesses
Ecological Footprinting	• Conceptual simplicity • Allows for comparative analyses • Effective heuristic and pedagogic tool • Focuses on the finite dimensions of human activity and the role played by trade in distributing ecological resources • Although it is not a dynamic modelling tool, if used in a time-series study, it can help monitor progress towards closing the sustainability gap as new technologies are introduced and consumer behaviour changes	• Allows for measurement of sustainability gap and ecological surplus • EF analysis provides secondary indices that can be used as policy targets, i.e. by asking the question how large is our ecological deficit and what can be done to reduce it?	• Footprint concept is too simplistic as model is static, whereas both nature and the economy are dynamic systems • It has no predictive capability • May underestimate actual ecosystem appropriation as not all consumption or waste discharge categories are included • Provides little information about socio-political dimensions, including distributional equity • Land use in EF is associated with single use only whereas, in reality, land use is multi-functional • Does not distinguish between sustainable and unsustainable use of land • Does not account for environmental effects of pollution or persistent residuals • Does not account for comparative advantages of countries and regions

Table 2: Strengths, applications and weaknesses of Ecological Footprinting (EF) (Rees & Wackernagel, 1996, pp230-232; Van den Bergh & Verbruggen, 1997, pp63-71; 1999, p62; Wackernagel et al., 1997, p13; 1999, p376; p389; Van Vuuren & Smeets, 2000, pp117-119; 127-129; Senbel et al., 2003, pp86-87; McDonald & Patterson, 2004, pp5-8)

Methodology	Strengths	Applications	Weaknesses
Integrated Assessment	• Allows for visual analysis and 'joined-up thinking' • Allows for estimation of current and desired trends as well as the divergence or convergence of such trends across a number of sectors • Sectoral indices can be summed to give an aggregate index • Can be applied across a range of spatial scales, including city-regions, national economies or supra-national entitities • Amenable to Strategic Environmental Assessment (SEA) and can be used to assess policies, plans and programmes (PPP) • May be used to monitor changes in trends over time • Indicates horizontal and vertical cross-sectoral effects • Aids policy-makers and stakeholders • Indicates critical indicators for which policy measures should be introduced, i.e. objective focussing	• May be used to link demand, supply and emissions in systems mapping and analysis of energy or transport • May be used for accounting of environmental or economic stocks and flows • May be used for impact assessment and strategic appraisal • Provides a structure of causal chains for indicators • Aids mental models and value systems in discourse and institutional analysis	• It makes linear projections, whereas trends may be more complex and exhibit dynamic behaviour • Data requirements for indicators, i.e. some critical indicators may not be selected due to lack of data • Value judgements and subjectivity in selecting indicators • Multiplicity and technical indeterminacy • Does not indicate threshold levels • Does not indicate nature of policy measures that should be introduced • Difficulty in determining quantitative policy measures and sustainable development targets, particularly with socio-economic indicators

Table 3: Strengths, applications and weaknesses of Integrated Assessment (IA) (Ravetz, 2000a, p45)

	1996	**2002**
Great Britain	0.181	0.19289
USA	0.0217	0.02094
Rest of the World (OECD Total)	0.06377	0.07671
Germany	0.006465	0.01809
France	0.013587	0.01577
Netherlands	0.02878	0.03
Italy	0.006297	0.003785
Belgium	0.005895	0.00645
Spain	0.006087	0.006974
Total	**0.334**	**0.372**

Table 4: Carbon Production per Capita Associated with Imports of Food Items per Major Trading Partner, 1996 & 2002 (Tonnes)

	1996	2002
Coking & Bituminous Coal	45,370.332	35,648.118
LPG & Ethane	1,638.338	1,638.338
Kerosene	1,721.148	3,442.296
Gas/Diesel	58,006.3823	64,640.175
Heavy Fuel Oil	70,957.1316	66,682.6056
Electricity	275,515.2	365,238.9
Natural Gas	103,302.08	100,890.3
Gas/Liquids from Biomass	3,078.24	3,148.2
Total	559,588.85	641,328.93
Carbon Emissions Per Capita	0.15432	0.16372
Ratio of (Production – Exports) to Production	0.74238	0.72795
Carbon Emissions Per Capita Irish Resident	0.11456	0.11918
Expenditure Ratio	0.8756	0.8756
Carbon Emissions Per Capita Limerick Resident	**0.1**	**0.104**

Table 5: Carbon Production Per Capita Associated with Production of Food Items in Ireland, 1996 & 2002 (Tonnes)