ECO-REGION NW

Position paper 5:

REGIONAL INDUSTRIAL ECOLOGY AND RESOURCE PRODUCTIVITY – BENCHMARKING & INNOVATION

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Introduction

There is a topical debate on how far ***industrial innovation*** can further the goals of ***industrial ecology***, in terms of physical resource productivity, waste minimization and closed-loop material flows. One way to approach this is through analytic modeling and benchmarking of the interactions of economic flows with environmental flows. Such modeling can potentially work well at the regional scale, where physical flows can be fitted with economic activity, and with potential for recycling, industrial symbiosis and other forms of integrated resource management.

However, experience shows that analytic modeling and benchmarking tools have to be situated within policy and business practices, if they are to be used and useful. It is also clear that few modeling or benchmarking tools are well equipped to deal with the complexities of supply chains, actors and networks, and evolutionary or structural change. However there at present rapid learning on regional resource productivity, which is forcing the pace of development and applications of such tools even before they are functional.

This chapter is a brief review of work in progress on the UK regional agenda for resource productivity, with an outline of two types of analytic models, and their potential applications to regional innovation systems. We first outline a resource productivity 'framework' for mapping the interactions of different forms of flows and capitals, in both economic, physical, and social forms. This framework helps to underpin a 'diagnostic toolkit', in the form of two modeling and benchmarking tools currently in development or on trial in the regions of the UK. Based on the REWARD programme and the Mass Balance programme, these are drawn at the regional scale, with the potential for extension to the local, sectoral firm and product levels.

Such tools have applications both 'before' and 'after' the innovation process, in benchmarking the potential or the impact of changes in industrial production or consumer demand. One topical application is to examine the interaction of the 'weightless' economy of ICT-based systems for resource management, with the 'weighty' economy of the resources, themselves. The this points towards further development of the models and their applications.

Context

The UK's national strategy recognizes the structural challenge of the goal of sustainable development, and aspires towards a far-reaching policy experiment in 'Sustainable Consumption and Production'. In practice this is seen not so much as a strategy, as a framework for future policy development (HMG 2005: Strategy Unit 2004: SDC 2004). Within this agenda, the 'production' side can be interpreted in terms of 'resource productivity', which promotes the themes of eco-efficiency and dematerialization as a driver for business competitiveness, risk minimization, shareholder value and others (Performance & Innovation Unit 2001: Leadbeater 2001).

This theme of 'resource productivity' follows several strands in industrial ecology ('IE') thinking. One is the inter-dependence of material flows and waste exchanges in industrial clusters (Chertow 2000). Another is the 'factor four' approach which focuses on the overall reductions in environmental impact, as a combination of both supply sides and demand sides (Lovins & Weizsacker 1998). This then points towards the 'frontiers' of technological innovation and the benchmarking of firms and sectors in relation to best or average practice (Tyteca 1998). A further approach is the 'eco-modernization' of industrial sectors (Ravetz 1999: Mol 1996), and the implications for new approaches to environmental regulation (Gouldson & Skea 1999). There is consensus that these approaches aim to meet both economic and environmental goals, but also a realization that they do not always coincide.

Meanwhile there is an emerging agenda for regional development and governance, across the diverse geography of the UK. This has seen the growth of institutions such as the Regional Development Agencies (RDAs) (Roberts et al 2004): the growth of practices such as 'integrated appraisal' and 'Regional Spatial Strategies' (Haughton & Counsell 2003): and the general awareness of the regional scale in the sustainable development agenda. Key strands of the RDA economic strategies include industrial innovation, the role of clusters, market development and business competitiveness programmes (Cooke et al 2003). More recently, environmental management and pollution control technologies have emerged as a key theme for industrial cluster development (*Environment Agency 2003*)

The theme of this paper centers on the intersection of these agendas of regional development, industrial ecology, and business environment benchmarking – here titled 'RD-IE-BE'. The concept mapping below shows the industrial ecology theme at the center of two axes: firm scale to regional scale, and environment to economy (Fig 1). The RD-IE axis shows the emerging environmental technologies as a agenda for clusters, market development and business competitiveness programmes. The IE-BE axis shows the emerging agenda for the benchmarking of environmental performance in business: this works for both the 'push factors' of regulation, cost and liability, and for the 'pull' factors of improved image and new markets. Thirdly, the BE-RD axis then relates the business performance metrics back to the scale of the regional economy, and points towards regional policy initiatives to promote improvements.

Fig 1

At the center of this concept map is the potential for 'innovation' as a catalyst which enables positive and holistic change in each of the dimensions. In common practice a regional innovation system is conceived as centred on the 'development and diffusion of new technologies' (Metcalfe 1997:461), and the systems of agencies, networks and subsidies are geared accordingly. However the goals of regional sustainable development and its application in terms of IE, suggest a wider perspective which aims to expand the general frame of reference or 'techno-economic paradigm' (Green et al 1999). This can be seen as constituting several kinds of paradigm shift, in particular (Freeman 1992):

- local and global threshold and limits for environmental resources and assimilation capacity;
- economic growth as a means to an end of social welfare (however that may be defined).

All this suggests the need for better analytic tools to examine the intersection of the three themes of 'RD-IE-BE' above, in the general spirit of evidence-based policy-making. Such tools might take the form of technical diagnosis, comparitive benchmarking, quantitative analysis and multi-criteria decision support methods. Such diagnostic systems are currently being developed in the UK as

'databases' and ***'models'***, mainly focused on the quantitative measurement and scenario appraisal of regional production and consumption. Such a combined ***'toolkit'*** would aim at applications at the product scale, in terms of environmental impact through the supply chain: at the firm scale, in terms of environmental performance benchmarking: at the sectoral scale, in terms of indices for overall performance and comparison between regions: and at the regional policy scale, where the trends, targets and priorities for regional interventions may be assessed.

At each of these levels, there are baseline applications, in terms of monitoring and reporting: comparison of best and worse cases: and of incentives or barriers to individual firms. There is a role for future studies applications, in terms of trends, projections, alternative scenarios, targets and trend-target analysis (Ravetz 2000b). Such approaches can then be used in practice for evaluation and appraisal, in terms of the ex-ante and ex-post assessment of opportunities, interventions and technological improvements.

At present it is clear that such analytic tools are in their infancy: the sophistication of financial accounting can be contrasted with the data scarcity of most physical models, although even such national economic accounts are relatively recent (Ekins & Simone 1999). It is also clear that the analysts and modelers comprise only one element in a combined learning and innovation process, involving firms, consultants, regulators, academics, consumers and others. The approaches described here are at the start of a long process.

A resource productivity framework

At the center of the relationship of RD-IE-BE is the theme of 'resource productivity' (RP). Resource productivity has many definitions and many incentives – as a driver of business competitiveness and quality management, as cost saving or dependency reduction, and as a measure of industrial innovation. A narrow definition would see RP as a measure of economic output per unit of input, whether these are in terms of finance, labour or physical units (Performance & Innovation Unit 2001). A wider perspective would look beyond the 'output' to that of 'outcome' in terms of human welfare achieved.

To pursue this wider perspective on resource productivity, we demonstrate a general framework for its definition and quantification. This has been extended from the 'Integrated Sustainable Cities Assessment Method' (ISCAM), a package of methods and tools for systems mapping and modeling (Ravetz 2000). The discussion in this section includes firstly an overall framework for the interaction of economic, environmental and social flows and capitals. Then we examine how this can be applied to various definitions of resource productivity, and to the firm and product level.

A set of cycles

A useful mapping, if not an explanatory theory, to identify the interaction of economic, environmental and social flows and capitals is shown in the diagram below (Fig 2). This shows several kinds of flow, which can be conceptualized and potentially modeled as cyclic processes:

Fig. 2

- ***Resource / material flows***, from extraction, manufacture, use, disposal and return to the environment
- ***Economic flows***: shown as the conventional 'economic' circular flow of money / capital.
- ***Social flows***, concerning the cycle of labour, production, consumption / 'utility' / 'outputs', and social welfare 'outcomes'. It should be noted that this is strictly a heuristic mapping device, not a social theory, and any deterministic modeling on this theme is of course more problematic).

The diagram also shows the generalized policy goal or normative direction for each of these, in the light of the concepts of 'dematerialization' (Leadbeater 2000) and 're-socialization' (Robinson & Tinker 1996):

- ***Resource flows:*** to MINIMIZE impacts, in order to maintain life support systems
- ***Social flows:*** to MAXIMIZE social welfare and social capital
- ***Economic flows:*** to OPTIMIZE, in the light of the above

The integrated framework here of course is vastly simplified, in order to identify the topology and fundamental interactions between each of the circles. Its use is mainly as a conceptual tool, not necessarily as explanatory theory in itself. In particular it helps to understand the different types of interaction between physical, economic & social systems / processes. We should also note that there is nothing fixed about the division into three circles. One current initiative uses four types of capital (natural, human, manufactured and social), in a prototype evaluation framework for sustainable regional development (GHK et al 2003).

The conceptualization of the circular processes or 'cycles' may be conceived as running in either direction, depending on the issue at hand, which is a recurring theme in system dynamics methodology. For the environmental cycle, for instance, there is a fairly clear path in terms of mass transfers, from primary material extraction, to use, to waste, and back to the biosphere. However there is also an opposite kind of causal path, whereby the demand for materials at the point of consumption then motivates or 'causes' their extraction through the medium of market pressures. The circular flow of money may be equally bi-directional in the nature of its cause and effect.

Identifying 'capital'

Where we can identify assets or resources or stored / maintained qualities, whether these are economic, environmental, or social, then this correlates with the concept of 'capital'. In economic terms this is fundamental and quite familiar, subject to the many possible financial attributes of liquidity, interest, equity, time preference and so on. For environmental capital assets it is less clear: it may be tangible in economic terms (e.g. a hectare of commercial forestry), but quite volatile or fuzzy in social capital terms (e.g. a hectare of mixed community woodland). This perspective points to the way that 'capital' is not necessarily a straightforward quality such as money in the bank, but more akin to the potentiality or latent qualities for mobilization, qualities which are effective for each of the circles in relation to the others (economic, environmental or social). In other words, just as economic capital is only 'realized' when the money is drawn from the bank, environmental capital is only 'realized' when brought into social or economic processes.

Where we can identify types of 'capital' which are mobilized by combination or transformation with another type of capital, then we have a generic typology of possible interactions between each of the circles. The various points 1-6 on the analytic diagram below, represent the range of possible generic interactions between flows in the economy, environment and society. This provides an overall template for more detailed modeling and analysis.

	PHYSICAL CYCLE		
1	**Physical resources extracted and enter economic system**	**4**	**Physical environment enables / mobilizes social activities & systems**
2	**Physical resources are processed by labour in the economic system**	**3**	**Physical community resources mobilized by economic system & capital**
3	**Physical resources are sold from economic system into social consumption**	**2**	**Physical resources transformed into independent capitalized commodities**
4	**Physical resources leave social system as waste, to return to ecological system.**	**1**	**Physical resources leave economic system as wastes, to return to ecological system**
	ECONOMIC CYCLE		
5	**Capital mobilizes social system to generate productive labour.**	**1**	**Economic production: capital mobilizes physical resources**
3	**Capital uses labour, to act on physical resources in economic production.**	**6**	**Mobilized resources are processed with added value from labour input**
6	**Physical goods & commodities, are the result of economic production**	**3**	**Economic value mobilizes social system independent of physical resources**
1	**Economic value / capital is generated, independently of physical / social effects.**	**5**	**Economic value / surplus / accumulation disengages from social system**
	SOCIAL CYCLE		
4	**Social system engages with physical environment in time & space**	**5**	**Social system mobilized as labour, by economic capital**
6	**Social system mobilized, via capital in economic production**	**2**	**Mobilized labour in economic production, to process & transform physical resources**
2	**Social system conditioned by non-material consumption / production**	**6**	**Social consumption of physical resources, after economic activity**
5	**Social experience, independent of economic consumption / production**	**4**	**Welfare gained in social system, after consumption / engagement of physical resources**

Table 1: generic interactions in resource productivity

The generic interactions between economic, environmental and social cycles are shown on the diagram (Fig 3). The flow in each direction is shown as far as this can be visualized. The table below shows a more complete listing of each interaction or crossing point in each system cycle.

Fig.3

Mapping resource productivity

A more evolved perspective on RP looks at the interaction of each part of the cycles of economic, environmental and social systems, and the mobilization or impact which is effected at each point. One analysis of the regional metabolism in construction minerals, for instance, shows the different kinds of capital involved (McEvoy, Ravetz & Handley 2004):

- Economic capital mobilizes industrial plant, to extract minerals to provide construction concrete, which serves the demand for social housing.
- Employment is generated in local quarries to supply distant minerals markets, which promotes local resident spending, while creating disturbance in a National Park area and reducing the attraction to tourists.

The social system shown here is often left out of conventional resource productivity calculation, as it is often complex, volatile and difficult to quantify. For instance, it would be simple to assume that the 'value' of construction minerals is equal to their commercial value at the retail or wholesale stages, until we consider the longer term sustainable development issues (Hammersley 1996). This valuation may be workable and plausible, up until the point at which the social system and its embedded 'capital' / 'value' is predominant: i.e. the 'value' of the undisturbed landscape: or the 'value' of the finished social housing to the community and neighbourhood. This of course raises a challenging agenda for institutional ecological economics, and the measurement of externalities (Ravetz 2000b, pp235: Foster 1997: O'Connor et al 1999).

The framework above can be used as a basis for mapping different types of RP, in terms of ratios between the various key stages on the economic, environmental and social cycles (Fig 4)

Fig 4

The mapping shown here is not fixed and final, but shows the possible scope of a larger set of resource productivity indicators:

- A: Primary resources / firm capital employed
- B: Primary physical inputs / outputs
- C: environmental impact / gross turnover
- D: Consumption 'utility' / final resource flow
- E: Intermediate resource flow / value added
- F: Material throughput / labour
- G: Labour productivity: net output / employee
- H: Primary physical inputs / material throughput
- Total material requirement / total GDP

Naturally, the selection of a practical set of performance indicators for any real industry, process or product can be difficult. The complexities of supply chains, labour effects, social impacts, inter-generational effects and so on, rapidly exceed the available data and the willingness to collect it. In the minerals case study referred to above, there was lengthy debate from senior industrialists on the choice of appropriate indicators, to represent different stages in the supply chain for different types of minerals with different applications.

Application to firms and products

The simplified framework above can be seen to represent an ideal theoretical case, where one firm uses one material to make one product with one worker, with one type of social outcome. In reality of course, each of these domains can be vastly complicated by supply chains, institutional effects, market effects, global / local externalities and so on. This is then the agenda for business benchmarking, which can be applied to environmental management, environmental performance, or resource productivity metrics in various ways. First we look at the generic typologies in which any business may engage with resource flows, and hence resource productivity. This works generally within the input-output methodology for inter-industry transactions and the conceptualization of upstream / backward linkages, and downstream / forward linkages (Isard 1989: Giljum & Hubacek 2003).

1) Direct production impacts: direct or on site consumption of energy / resources, in the processing and manufacture of physical products. This applies more to material- or product-intensive businesses in manufacturing sectors, for instance the manufacture of plastic containers.

2) Indirect production impacts: embedded energy / resources in the upstream or downstream stages of the supply chain. This applies more to processes at one stage in a more lengthy and complex supply chain, for instance the impacts of manufacturing above may be outweighed by the production of the plastic itself.

3) Induced production impacts: embedded energy / resources where the material flows are removed at some distance from the supply chain. This applies to producer services or consumer services, for instance an environmental consultancy which advises on the manufacturing process above.

A similar breakdown can be identified on the consumer side, for both households and the public or non-profit sectors, i.e. direct, indirect and induced impacts. Such a typology can then be applied to the question of resource productivity, with the added dimension of what is here termed ‘resource flow proximity’, i.e. the distance from the main resource flow path in terms of number of supply chain links.

	Externality / factor inputs	Backward linkages	Activity	Forward linkages	Externality outputs
Direct MFA	**Energy, transport**	**Primary materials & components**	**Processing & assembly**	**Assembly, distribution, retail**	**Products & by-products**
				Value added services	**Waste, emissions**
Indirect MFA					
Induced MFA			**Value added services**	**Consumption**	**Post production waste etc**

Table 2: resource productivity benchmarking upstream and downstream

To summarize, this resource productivity framework so far has deliberately been simplified in order to map the key features. We have said little here about the consumption side: recent work under the UK Sustainable Consumption & Production programme looks at what might be termed the counterpart agenda of 'resource consumptivity' (Jackson 2004). For the present paper the RP framework then serves to underpin a set of regional models and information systems as below.

Resource productivity models

One response to complex problems – not the only one – is to simplify with a model. This brings its own pitfalls and drawbacks: it also brings into focus the pre-conceptions of the model makers, the model users, the social construction of knowledge which is formalized in the model, and a host of other considerations. (Shackley & Wynne 1998: Ravetz 1998). Here we focus on two related examples of models for regional consumption and production, currently in prototype development and testing around the UK.

The REWARD programme

The conventional approach to regional analysis has at its core an economic or econometric base. This has recently been extended to include environmental and resource issues in a current regional programme in England and Wales. The REWARD programme ('*Regional and Welsh Appraisal of Resource Productivity & Development')* aims to provide an information base for resource productivity initiatives at the regional level[1]. It was formed by a partnership of Regional Development Agencies and similar bodies between 2002-4, and now forms the beginning of a longer term programme[2], with three main objectives:

[1] Full details, documents and databases are available as of end 2004 on www.reward-uk.org

[2] As of end 2004, the partnership includes: Environment Agency; North West Development Agency (NWDA); North East Regional Assembly (NERA); South East England Development Agency (SEEDA); East Midlands Development Agency (EMDA); East of England Development Agency (EEDA); Advantage West Midlands (AWM): and the National Assembly of Wales (NAW). Other contributors include Cambridge Econometrics, AEA Technology, Caleb Management Services Ltd, and the Centre for Urban & Regional Ecology at Manchester University.

- 1) Development of a computer model - the REEIO ('Regional Economy-Environment Input-Output model'). This provides a new level of analysis of the effects of economic trends and economic policies on resource use and environmental pressures.
- 2) A research programme and database on the resource productivity of the regions of England and Wales, and the implications for policy and business.
- 3) An applications and capacity building programme in each of the regions of England and Wales – enhancing strategic intelligence through workshops, training, toolkits, information systems, analysis and communications.

The REEIO model

The REEIO software model provides a relatively detailed quantitative analysis of regional strategy and policy appraisal, providing a solid technical foundation for other analysis, and links to other technical models and databases. The REEIO is based on a detailed econometric input-output model of each regional economy, based on the widely used 'Local Economy Forecasting Model' and its parent the MDM model of the UK economy (Lewney 2001: Brettell 2003). This uses a 50 sector economic classification mapped onto the 123 national SIC classification, and the labour market is shown in six types of employment and 25 types of occupation. The REEIO then links economic and employment changes with key environmental and resource pressures:

- Waste sector: arisings from household, industrial / commercial, construction, agriculture etc: biodegradeable, non-bio-degradeable, inert and non-inert compositions: disposal routes to landfill, incineration, recycling / re-use.
- Energy sector: demand from households, transport, industrial / commercial activity: energy supply is by 13 sectors and 6 fuels.
- Air emissions: including greenhouse gases, $SO_{x,}$ $N0_x$, VOCs, PM etc:
- Water sector: aggregate water demand metered or non-metered is related to households and to economic activity:

The user inputs are arranged in a series of 'what-if' scenario assumptions, from overall population trends to the details of waste or energy management. These are generally arranged as policy inputs or technological change, but short term interventions, projects and shocks can also be simulated. The outputs can be taken to spreadsheets for charting, and further analysis on policy or business implications. To cover more detailed questions such as economic clusters, transport strategy or environmental technologies, a series of 'off-model' components is being developed in the form of smaller spreadsheets. A key resource is a comprehensive database of economic and environmental indicators, trends, projections, and scenario inputs for each region. One of the main components is the 'Linking-Up' study, which looks in detail at the policy applications of the model, in terms of future studies, strategic planning, evaluation / appraisal, and policy training (CURE 2003). One of the route maps produced by the Linking Up study shows the range of applications of the REEIO and related models (Fig 5).

Fig 5

The model so far has been applied in several regions including the North West of England, where it helped to analyse the trends, projections and the potential for commercial/industrial waste minimization (CURE et al 2004). This aimed to quantify the opportunities for waste minimization by increasing the scale of activity in business-environment programmes. The study process included a regional workshop, a detailed report on modelling and regional initiatives, and the setting up of a forum to take it forward. This also aimed to link the REEIO system to the material flow analysis method in the next section, although this turned out to be difficult without the new waste datasets currently being developed by DEFRA.

Mass balance approach

An assessment of material and energy flows within a defined boundary is termed a ***Material Flow Analysis (MFA)***. This looks at the material inputs to a region in terms of raw materials and products, and at outputs in terms of waste and emissions, plus any changes in stocks. The analysis focuses on the consumption of goods and services by households and the commercial sector, including materials directly used and consumed. It may also look at 'hidden' material flows including ores and wastes from extraction or harvesting, energy used for extracting, transporting and producing materials: and greenhouse gas emissions from energy use. This kind of data is generally arranged in terms of 'consumption sectors', i.e. the material requirements of the functions generated by final consumer needs, rather than the detailed breakdown of economic 'production sectors' in the REEIO model and most economic accounts. As a result of these two complementary approaches, a number of key physical indicators can be generated (Eurostat 2002: Bringezu & Schutz 1999: Brunner & Rechberger 2004):

- ***Direct Material Consumption*** (DMC): the total amount of materials directly used in the regional economy and consumed in the region, i.e. excluding exports.
- ***Total Material Consumption*** (TMC): the total material use associated with regional consumption, including DMC together with the indirect or 'hidden' material flows generated by that flow. Again, this excludes exports and their associated indirect flows.
- ***Carbon dioxide emissions*** (CO_2): the most common and easily aggregated resource flow and the most topical as the largest single anthropogenic cause of climate change.
- ***Ecological footprint*** (EF), usually measured in 'global hectares per person'. This is calculated from the CO_2 emissions, plus other impacts on land use. This is allocated on the 'consumer responsibility' basis, i.e. an aggregate measure of all impacts from all flows which are implicated in the delivery of products to the final demand from households.

Material flow models in the UK

Over the last 5 years, a large scale 'mass balance' research programme has been sponsored by the waste company Biffa plc, with the opportunity of funding via the UK Landfill Tax Credit Scheme. This has focused on selected industrial sectors: a range of substances and products: and a selection of regions or sub-regions.[3] A coordination unit has set up a common database using the European CN (Classification Nomenclature) (Linstead & Ekins 2003). There are two main approaches:

- Production-centred mass balance: this takes a sectoral approach to raw materials and manufacturing, and includes exports plus regional final demand. This is more compatible with the REEIO model approach.
- Consumption-centred mass balance: this focuses on the products and services delivered to final consumers in private households or government, and traces the direct and indirect material consumption along product supply chains, with their impacts, which could be anywhere in the world. This approach is suited to a LCA method, and its simplified version the Ecological Footprint.

In principle a combined and integrated system should be developed with both production and consumption as part of a whole. However, existing data is generally inadequate for making detailed links between one approach and the other. For instance current UK waste data does not contain details of its material content, its industry source, or its location of origin. The consumption data now being assembled from a variety of databases including PRODCOM, COICOP and the IVEM energy database, does not have detailed information on the waste arising from each stage in the supply chain, or its material content, or the inter-industry transfers of materials and waste. However there is enough current data to at least provide an outline 5-stage model of the UK and regional economy in material flow terms (Fig 6).

Fig 6

- The framework is organized in a 5 stage process, corresponding roughly to the primary, secondary, tertiary, demand and 'externalities' classification of economic sectors. Each of these types corresponds roughly to a different kind of relationship between material flow and economic value.
- Various kinds of waste streams are shown by the shaded boxes on the right hand side, coming off each of the stages.
- Various inputs of energy and transport are also shown at each of the 5 stages.
- ***Resource productivity,*** i.e the useful outputs per unit of input, can be measured at each stage of the production chain, in the context of the mapping above at Fig 2-4.

Although this chart contains a range of material flows types, it is of course simplified compared to the real situation where many materials are used to make many products, at many intermediate stages, in many sectors, with many environmental inputs and outputs. There is little data available in any coordinated form, for these many interactions. Recent work uses a proxy approach with environmental multipliers on economic supply-use tables, coupled with allocation of expenditure data via the COICOP database, and the material production data in the PRODCOM system, to provide a basic physical input-output table for the UK and its regions (Barrett & Wiedmann 2005).

[3] details available as of end 2004 on www.biffaward.org.uk: www.massbalance.org

A system of ‘activity modules’ and satellite accounts then links the monetary and mass units to functional units such as km traveled, houses built or food supplied (CURE 2005).

The REAP model

The REAP (‘Resources & Environment Analysis Programme’) software model and database translates the above methodology into a working package. This is an adaptation of the LEAP model developed by the Stockholm Environment Institute, used in over 40 countries around the world. The methodology is based on the above material flow analysis of production and consumption, with a database of trends, projections and alternative scenarios, and policy options for economic development or environmental management under a range of alternative assumptions on population, with proxies for economic development, technology innovation, price and fiscal effects and so on. The REAP scenario modelling system is arranged around a ‘functional’ concept, with four types of components:

- ***Population and demand***: factors that affect the overall size of the economy, labour force and consumption: regional migration, demographic factors, and household incomes / savings.
- ***Technology and production***: factors that affect the share between economic sectors, and the transactions between each of the sectors: e.g. the size of the waste management sector, and its use of transport services.
- ***Productivity and eco-efficiency***: the resource intensity or the amount of waste / emissions produced for each £ of turnover in each sector: e.g. the waste from construction activity.
- ***Environmental management***: for some topics, there are further choices to be made: e.g. waste disposal / recycling methods.

The modelling system starts with the form of a simple environmental accounting model, organized in principle around the 5-stage mass balance framework above. However in practice the data at each stage are in different types of units – raw materials at the primary stage, products at secondary stage, composite items and services such as floorspace or transport kilometres at the tertiary and demand stage. Also, to design scenario settings with policy relevance involves a wider set of parameters than a purely MFA- mass balance model can deliver. The way forward is seen as a loose-coupled modelling framework, where the core mass balance model is linked to a range of other models with compatible formats:

- Econometric-based physical IO model, which provides the environmental multipliers
- Materials, products, components and environmental coefficients model / database, adapted from the PRODCOM system
- Activity sectors and policy issues at the regional & urban level, including urban development, land use, housing, transport etc.

This is generally based on the ISCAM modeling approach, which provides a consistent format for the ‘off-model’ calculations needed to link policy inputs with the mass balance information (Ravetz 2000). This is based on the ‘decomposition’ approach to disaggregating compound trends and dynamic relationships into discreet factors (Ekins & Barker 2001: Kaya 1990).

Applications to benchmarking

One of the main applications of the REAP tool and the regional production-consumption framework is a framework for benchmarking the environmental performance of businesses. In this case the role of the benchmarks is to identify the interaction of economic activity with environmental impact / resource consumption, within the typology above of direct / indirect and induced resource flows. There are several recent approaches to this:

- The ENWORKS on-line data capture tool is focused on the 'opportunities' for better practice which have been discussed in firm-level site visits and other outreach work. This then serves to track progress in the pipeline of concept, targets, feasibility, implementation stages and so on. There is a drawback in that the analysis only counts energy, solid waste & water effluent production, but is focused on monetary values rather than physical quantities.
- The ASSESS on-line environmental management package focuses on environmental policy, but also contains a trial application of direct 'mass balance' questions. Experience shows that these are difficult to translate for different business sectors, and difficult for business to find data for without direct pressures or incentives.
- The PERFORM database of firms across the EU in selected industrial sectors is very comprehensive and analytically sound. However difficulty was found both in getting the primary data, and in finding applications and users for the completed work (Berkhout & Hertin 2004).

The experience so far is that on-line questionnaire type survey forms work most effectively with human contact as backup, where data collection is very easy, and where there are strong incentives for data collection. However on-line benchmarking is often technically complex, costly and prone to these failures. Hence a hybrid approach is followed for the REAP / Eco-Region benchmarking scheme, between manual and on-line access: it is also triangulated between production (sectoral) and consumption (product) level analysis. The template under development contains, as per the 'Rubik's cube' visualization below (Fig 7):

Fig 7

- Environmental factors in waste, materials, transport, energy, water, minerals, toxicity burden if known etc
- Economic / social factors: GDP / turnover, GVA, employees, capital investment, other EHS / corporate responsibility
- average / best practice for similar firms / products
- average / worst / best practice for the sector and sub-sector
- trends, projections, targets and trend-target distance for the key factors above.
- comparison wherever possible with regional thresholds, pressure points, limits, goals and targets.

- More qualitative information on opportunities and threats, specific to each business type in each sector.

Applications to innovation systems

Regional innovation in context

At the regional level there is often a strong correspondence and 'fit' between physical functions, social identity, economic units and political territories. Because of this the regional level brings opportunities to improve on the current state of policy fragmentation and to make new linkages for the SD agenda, between the local and the national scale, where economic and spatial policy may be more flexible (Gibbs 1999). The emerging agenda for 'sustainable consumption and production', itself a fuzzy combination of aspiration and actions, brings in a much wider scope than the conventional focus on economic growth:

- Production side: including goods, services, public services, environmental capital;
- Consumption side: the 'outcomes' in terms of human welfare, social cohesion, and the culture and psychology of consumers, clients, citizens, institutions;
- Quality of life / added value: a wider view of the interactions of social, economic and environmental capitals and flows, as represented in the RP mapping in Section 2.

Each of these represents a challenging agenda for institutional change or shift in 'techno-economic paradigm', via a process of innovation, either indigenous or catalysed by public interventions (Freeman 2002). Such a shift can be observed at the regional scale in the UK and EU, in terms of strategies for regional sustainable development, and emerging concepts for integrated planning and management for energy, waste, physical resources and so on. In order to facilitate such physical systems, integrated concepts are also emerging for finance and investment, governance and accountability, planning and management, monitoring and mapping, technological diffusion and so on. The point here for the RD-IE-BE agenda, is to highlight the many dimensions of innovation which may be involved in such a programme, beyond the conventional boundaries of bringing technology to the market-place:

- Innovation in institutions to handle such networks and partnerships;
- Innovation in financial models, trading schemes and market developments;
- Innovation in consumer and public services on the demand and consumption side
- Innovation in social enterprise and citizen responsibility to enhance social capital and cohesion;

- Innovation in logistics and supply chain networks to enable integrated resource management.

Such a broader picture has been linked back to a practical policy agenda for innovation in RP in a UK government initiative (Performance & Innovation Unit 2001). This identified market failures and institutional barriers to innovation, and then proposed a combination of market development, fiscal subsidies, capacity building measures, regulatory improvements and a strategic research program – not so much a new agenda as a consolidation of current thinking.

Structural change and resource productivity

The analytic models in Section 4 are focused on more on a quantitative and technical version of RP, and the wider regional agendas sketched here tend to cut across the formal boundaries of the technical models, with little relevance to the IO tables and similar structures. The question here is how far such technical models can help to inform such institutional innovation, or whether there are other more useful approaches?

One of the precursors to the REAP modeling system was a case study project on the regional metabolism of construction minerals, aggregates and inert wastes (McEvoy, Ravetz & Handley 2004). Based on a detailed analysis of resource flows and impacts, this pointed to the emergence of resource management thinking at the regional level and firm level, and the potential for more integrated 'resource management enterprises'. These would use advanced ICT to closely match supply and demand for re-used / recycled material in time and space, along similar lines to the 'industrial symbiosis' programme (Murata & Pearce, this volume). While there are prototype 'waste exchanges' now operating, it is clear that integrated resource management across the whole of the construction industry is dependent on innovation in institutions, management practices, regulatory and accounting procedures, design and specification constraints and so on.

This makes for an interesting contrast between the flow of materials represented by the resource models, and the dematerialized flow of digital information which is apparent in e-commerce. To pursue this we look at the theme of e-commerce as one powerful catalyst of such innovation in markets, technologies, institutions etc (Wilsdon 2001), where e-commerce is beginning to provide functions such as:

- Tracking of resource – waste demand, with specific in space, time, ownership,
- Matching demand with supply of new, re-used, recycled products and materials
- Interactive markets / shadow markets which enable trading between public, private, third and consumer sectors
- Lean design specifications to minimize waste and maximize effectiveness
- Integrated assessments of impacts, costs, values and benefits to different social and economic groups.

For the implications of this we could look at current analysis of the impacts of ICT / e-commerce, which tends to assume that markets, production processes, societies and so on will remain the same, except for the e-commerce effectd on speed and the globalizing scale of activity (OECD 2001: DTI 2002). In contrast it can be argued that e-commerce is already more instrumental in shaping much more fundamental and qualitative innovation and structural change, even while it is now used actively by a minority of consumers and businesses (Castells 2002):

- change in economic & market structures: i.e. instant / virtual markets, virtual distributed corporations, virtual stakeholder networks, consumer agglomeration markets, reverse auctions, consumer-consumer markets (C2C);
- change in institutional structures, i.e. relations between governments and markets, transparency & accountability of corporations;
- change in social and cultural norms: i.e. global media and styles: mobile telephony as a generator of social interactions;
- change in industrial and technological processes: i.e. just-in-time production, outsourcing, multi-agent contracting;
- changes in the logistics of retail and distribution are difficult to predict, but for instance the e-Bay internet trading system points to the possibilities.

Clearly e-commerce has the potential for rapid restructuring of markets, production and trading interactions, in new configurations at local, regional and global level. This can be characterized with the concept of intermediation – in other words the agencies and actions involved at each step in a supply chain or distribution chain (Pakko 2002). 'Dis-intermediation' represents the process of removing intermediaries, suppliers, brokers, distributors and other middlemen, who are rendered obsolete by the more rapid and cost-effective access of e-commerce. In contrast, 're-intermediation' is the process of establishing new agencies which act as brokers of information, access and capital in new patterns of trading and exchange. It is interesting to compare such an ICT-based supply chain perspective with current regional development perspectives such as the 'learning region' (Morgan 1996), or social perspectives such as the 'richness of cities' and their capacity for creativity and cohesion (Christie and Levett 1999).

This discussion might then continue in many directions beyond the scope of this paper. One is the re-configuration of global, regional and local supply chains as catalysed by the internet. Another is an institutional dimension on structural change and the facilitation of innovation. A third is the normative dimension on the internet, where the technological risks and impacts on vulnerable social groups and economies are seen as mitigated by public policy. Each of these can contribute to this paper's theme of resource productivity and the linking of analytic tools to innovation systems.

Linking analytic models to regional innovation systems

This section has raised a very challenging agenda, and it is clear that current analytic models are only at the start of a development process for the technical and quantitative applications, let alone the wider frame of structural and institutional change. However institutional learning is rapid with the current UK programmes of regional workshops on strategies, scenarios, and sustainable consumption and production. While such learning is not necessarily in a straightforward path, with parallel levels from awareness raising to target setting, various applications to regional innovation systems are beginning to emerge.

A useful way to identify the application potential is through a typology of regional innovation systems (Cooke et al 2003: Braczyck et al 1998). This characterizes the institutional style and context in terms of two axes: a business innovation axis ranges from 'globalist – interactive - localist': and a public governance axis ranges from 'grassroots – networked - centralized'. The applications of the resource productivity models can then be identified in terms of their functions in monitoring, benchmarking, forecasting and evaluation.

For the ***globalist*** business model, there are long term regulatory pressures and technological potentials which may be represented by the models; a centralist mode of governance would aim to relate these to firm policy targets and public interventions. Meanwhile for a ***localist*** business model, a more entrepreneurial approach may be more concerned with performance benchmarking and the related apparatus of incentives, training, market development and so on. A ***networked*** business model then focuses the resource productivity models on promoting regional scale industrial ecology, through supply chain analysis, waste exchanges and possible business-consumer trading. Each of these may work differently with a centralist style of government, where analytic models may be used to set targets and monitor progress: or a grassroots style of government, where the analytic data is used in a more entrepreneurial way. In each of these there are different approaches to linking the sectoral and firm agenda to that of regional resource productivity, and in linking the pattern of production through the market, to the pattern of consumption through a wider view on society and the environment.

Implications and future research

This paper has reviewed work in progress on the UK regional agenda for resource productivity, with an outline of two types of analytic models, and a review of the potential applications to regional innovation systems.

At present the agenda for 'resource productivity' in the UK is being expanded to that of 'sustainable consumption and production', and this is finding new possibilities at the regional scale of policy. Likewise there is growing demand from the corporate social responsibility agenda, for firms and sectors to monitor and benchmark their performance on a wider frame. Generally there is much mutual learning between the regional governance and the level of sectors and firms: there is also rapid learning between the environmental management and economic development professions: and between developers and users of the analytic models.

Each of these models cannot directly represent structural change and the innovation process, but provides valuable functions in monitoring and benchmarking, scenario modeling, and appraisal and evaluation, all of which promote and facilitate the process of innovation for improved resource productivity. Likewise they point the way towards new business and market configurations for the ideal integrated 'resource management enterprise'. Such enterprises may be oriented around a simple 'resource productivity' agenda, i.e. 'doing more with less': or a wider frame which includes social, economic and environmental interactions at each stage in their supply chain and product life-cycles.

All this points to several directions for future research. One concerns the technical dimension of model development, data management, and communicating to different parties for different purposes. Another concerns the business dimension of integrated technical information with management and market information. A third concerns the public governance in environmental management and economic development, and the task of integrating public policy information systems with those of the market. Finally, it is clear that there are new techno-economic paradigms emerging, which demand the integration of technical knowledge with a wider framework on sustainable consumption and production.

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Fig 1:

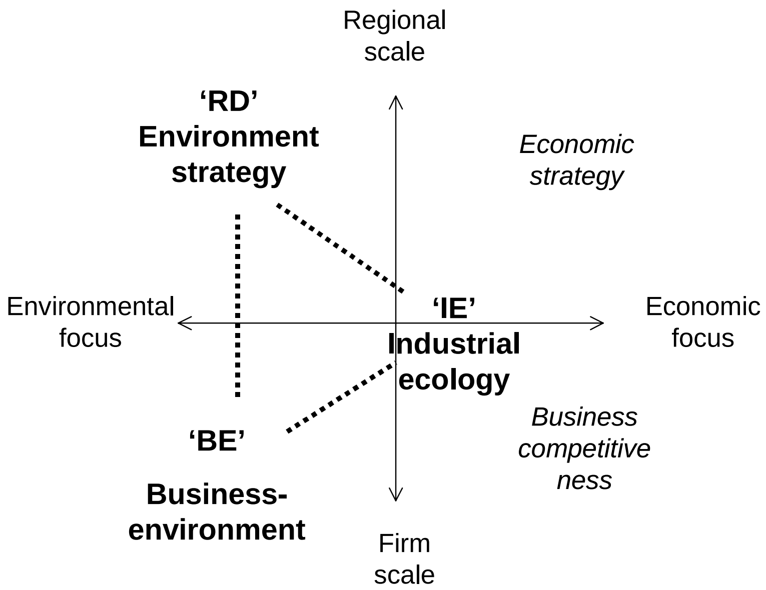
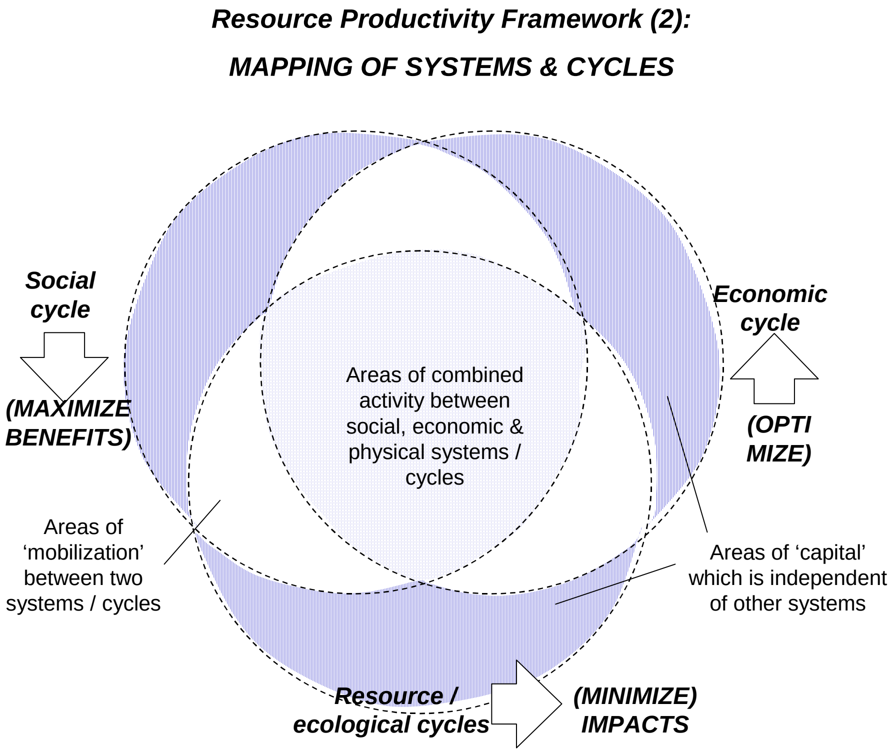

Regional scale
'RD' Environment strategy
Economic strategy
Environmental focus
'IE' Industrial ecology
Economic focus
Business competitive ness
'BE'
Business- environment
Firm scale

Fig 2



Resource Productivity Framework (2):
MAPPING OF SYSTEMS & CYCLES
Social cycle
(MAXIMIZE BENEFITS)
Economic cycle
(OPTI MIZE)
Areas of combined activity between social, economic & physical systems / cycles
Areas of 'mobilization' between two systems / cycles
Areas of 'capital' which is independent of other systems
Resource / ecological cycles
(MINIMIZE) IMPACTS

Fig 3.

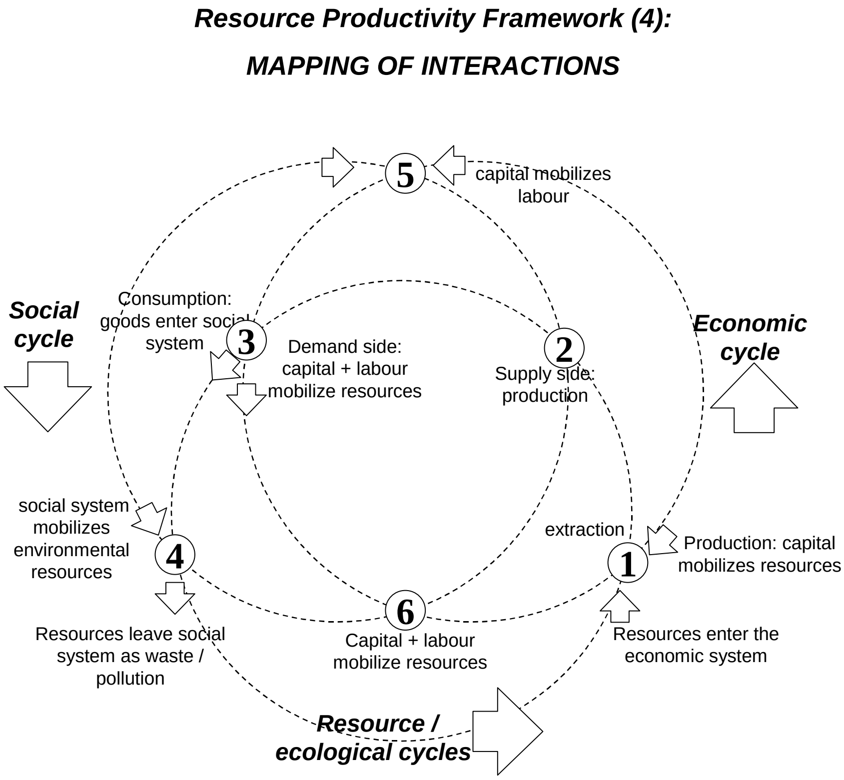

Resource Productivity Framework (4):
MAPPING OF INTERACTIONS
5
capital mobilizes labour
Social cycle
Consumption: goods enter social system
3
Demand side: capital + labour mobilize resources
2
Supply side: production
Economic cycle
social system mobilizes environmental resources
4
extraction
1
Production: capital mobilizes resources
6
Resources leave social system as waste / pollution
Capital + labour mobilize resources
Resources enter the economic system
Resource / ecological cycles

Fig 4:

Resource Productivity Framework (6):

MAPPING RESOURCE PRODUCTIVITY

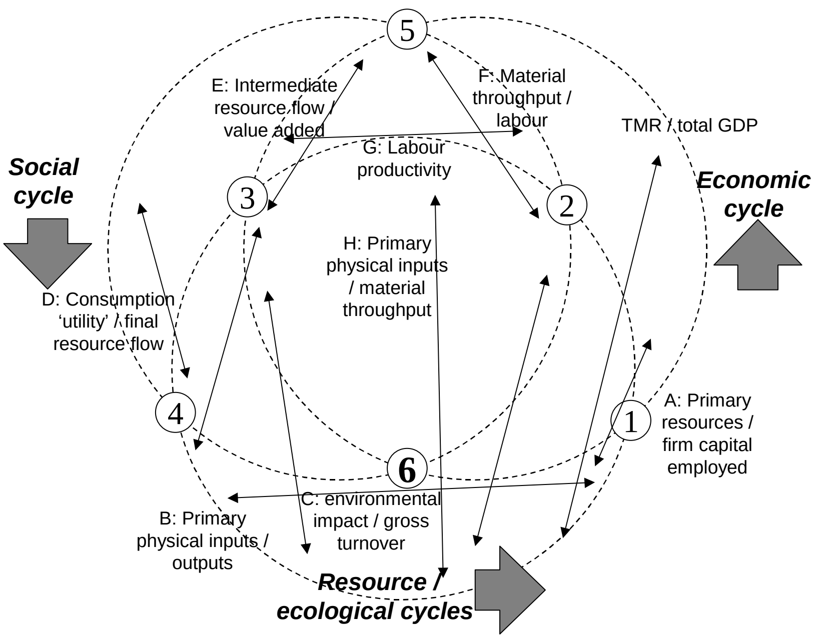
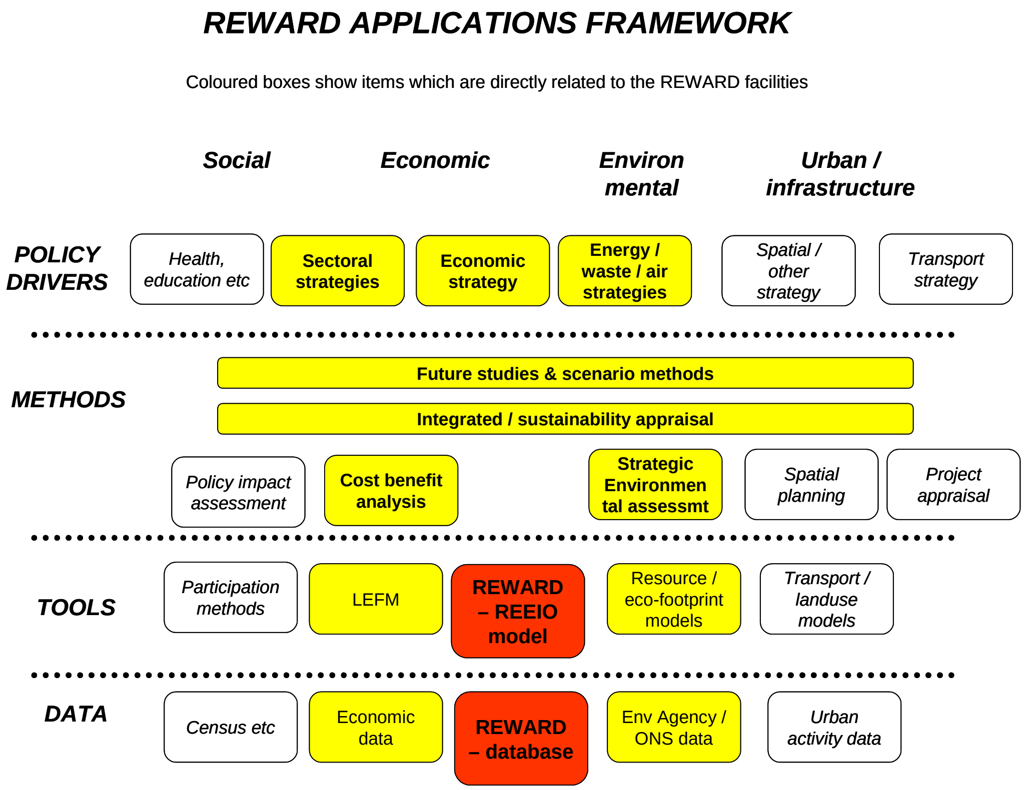


Fig 5:



REWARD APPLICATIONS FRAMEWORK
Coloured boxes show items which are directly related to the REWARD facilities
Social
Economic
Environ mental
Urban / infrastructure
POLICY DRIVERS
Health, education etc
Sectoral strategies
Economic strategy
Energy / waste / air strategies
Spatial / other strategy
Transport strategy
METHODS
Future studies & scenario methods
Integrated / sustainability appraisal
Policy impact assessment
Cost benefit analysis
Strategic Environmen tal assessmt
Spatial planning
Project appraisal
TOOLS
Participation methods
LEFM
REWARD – REEIO model
Resource / eco-footprint models
Transport / landuse models
DATA
Census etc
Economic data
REWARD – database
Env Agency / ONS data
Urban activity data

Fig 6:

MFA FRAMEWORK

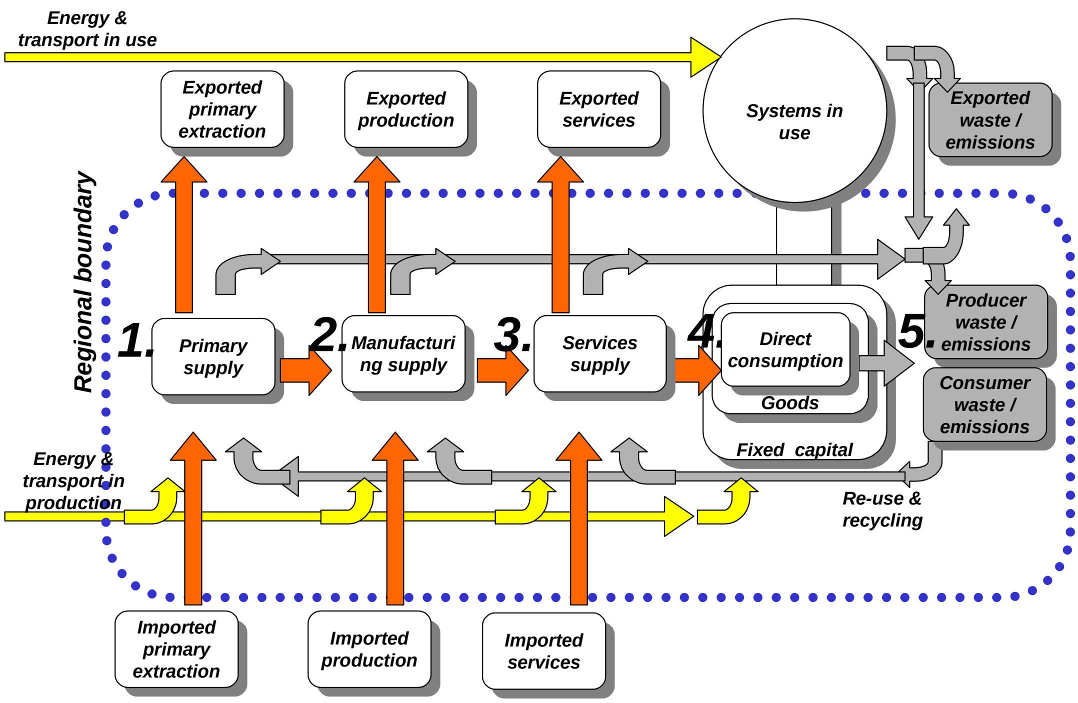


Fig 7:

ECO-REGION: BENCHMARK FRAMEWORK