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Towards Sustainable Management of Wastes: Results of a Modelling Case Study, and the Emerging Environmental Decision Support System Based on the Energy Footprint

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Abstract: Here we present an emerging EDSS, based on the energy and materials flow model for evaluation of alternatives for processing domestic and commercial waste. The input information for the model is obtained through a literature search, consultations with stakeholders, and also using a specially designed expert system (ES) - The 'Smart Waste Questionnaire'. The ES implements an IT-based interrogative data acquisition methodology built using a custom-designed expert system software and integrated databases. In this paper we present the results of an ongoing case study of the model's application to the management of specific waste types in the area of Southampton (England, UK). The model has been designed in Microsoft Excel and Visual Basic, which were chosen due to their user-friendly interface and common availability. In the model calculations, the input data on material flows, waste quantities and mass balances are combined with information on the energy requirements for different types of collection and processing systems for re-use, recovery, recycling and disposal, and on the energy benefits (e.g. production of heat by incineration or gas by anaerobic digestion, pyrolysis, etc.) of these options. The output shows the energy balance of the current practice, and also allows a comparison with a number of alternative scenarios. The results are directly applicable only for the study area. However, following certain modifications the methodology used may be easily applied elsewhere. Examples of the collected data and model simulations are given, problems with data collection and availability outlined, and limitations and implications of the study discussed.

Key Words: energy footprint, industrial ecosystem, waste management, glass, paper, expert system

1. INTRODUCTON

Complex integrative modelling studies help to enhance our knowledge of industrial ecosystems and are, therefore, an important prerequisite for sustainable development of Mankind (Korhonen 2001; Krivtsov *et al.* 2004a). Current progress in waste management is hampered by the lack of methods capable of evaluating sustainable practices. The tools used for comparison of alternative scenarios, involving collection, separation, and processing of waste fractions, must have a rigorous conceptual basis, and account not only for economic considerations, site-specific logistics and governmental guidelines, but also for environmental issues. In other words, society needs evaluation tools able to optimise (within given local, regional and global constraints) the existing waste management practices by minimising the required energy budget and both present and future environmental impacts.

Here we present an overview of the integrative research into the energy footprint of

Southampton wastes, conducted by the University of Southampton in collaboration with Southampton City Council, Hampshire County Council, and a number of relevant waste management companies and other Universities. This research integrates an extensive data collection programme, with the examination of data obtained through statistical analysis of a database, and with comprehensive simulation modelling analysis.

To analyse the characteristics of the overall energy footprint of Southampton wastes, the information obtained in different lines of investigation may be integrated by means of statistical and simulation modelling. In the analysis of waste management energy footprints, it is paramount to consider all relevant processes starting from the point where materials become wastes, until disposal and/or reprocessing. In particular, it is crucial to include both the energy consumed during processing and/ or disposal, and the energy consumed in transportation.

This paper, therefore, brings together the information obtained within the comprehensive analysis of data related to specific stages of the Southampton's waste cycle, and the results of simulation modelling, hence integrating the information separately obtained on various sub-systems in the analysis of the emerging interaction patterns observed. It sets the basis for an emerging environmental decision support system, i.e. EDSS (Rizzoli & Young 1997), aimed at facilitating the optimization of current waste management practices.

Integration of the software is often an important prerequisite for successful environmental analysis (Krivtsov *et al.* 2004b), and there is clear evidence of the ability for integrated environmental modelling to aid understanding and assist decision making in resolving complex environmental and natural resource management problems (Argent 2004). In particular, integration of an expert system and a database technology, equipped with a suitable interface may be useful for practical environmental applications, including those in waste and resource management (Liao 2003; Lukashch *et al.* 2001).

In the research presented here, the standard Microsoft Office Suite of programs was chosen to handle most of the data due to the predominance of the software, and, importantly, the facility to integrate the different applications (e.g. database, spreadsheet) without altering data. Integration of functions available in Microsoft Excel with a customised software written in Microsoft Visual Basic and Microsoft VBA allowed us to perform the analysis in an interactive mode within the model specifically compiled to represent the local conditions. This is achieved through the integration of standard and customised software, thus supplementing the capabilities of commonly available commercial tools by custom-designed tools reflecting the needs of particular tasks.

2. DATA COLLECTION

For the purposes of the research presented here, data collection involves using the information obtained through literature search, and extensive consultations with stakeholders, including, e.g., Southampton City Council (SSC), Hampshire County Council (HSC), Onyx Environmental, etc. A new extension of the research also incorporates the application of a specially designed expert system 'Smart Waste Questionnaire', intended to facilitate collection of the information related to

commercial and industrial wastes. It should be noted that the estimates of waste quantities, transport distances, vehicle and material characteristics represent the current assumptions incorporated in our modelling analysis. These estimates are based on the information available, and are continuously being improved to increase the predicting and interpretative power of our research.

3. MODEL DESCRIPTION

The model presented here considers all relevant processes starting from the point where materials become wastes, until disposal and/or reprocessing. Most importantly, the model accounts not only for the energy consumed during processing and/ or disposal, but also takes into consideration the energy consumed in transportation. The model has been compiled in Visual Basic linked to Microsoft Excel. Structurally, the model consists of interlinked submodels, with each sub model simulating a specific stage in the overall process. The most important submodels include

- Refuse collection and landfill transfer
- Kerbside collection
- Stage one transport (i.e., from consumers to collection points)
- Stage two transport (i.e., from collection point to processing plant)
- The processing plant
- Processed material transfer
- Manufacture

In the case of paper/card, however, an important consideration should be given to the incineration process, as removing of paper/card from the waste stream may result in a decrease of the wastes' calorific value. Although currently Southampton wastes are not incinerated, an incinerator is being built in Marchwood, and is due to become operational in the very near future. Therefore, an additional submodel describing incineration process has been incorporated into the model structure for the paper/card case study.

The subprograms representing separate submodels are called from the main program, and the total energy consumption is obtained by adding up the energy consumptions of the specific components returned by the subprogrammes. It should be noted that, as much as possible, parsimonious code is achieved by the reuse of submodels (Rizzoli & Young 1997). For example, one of the most reused submodels is the submodel calculating vehicle energy consumption from data on the vehicle load, journey distance, waiting and

handling time, fuel consumption per mile traveled, and the average speed.

Integration of the separate lines of investigation within the model's calculations is briefly demonstrated below on the example of two case studies assessing energy footprints of Southampton glass and paper/card. Further details of the study and the results obtained are given in separate publications (Krivtsov *et al.* 2003; Krivtsov *et al.* 2004a).

4. EXPERT SYSTEM Smart Questionnaire

Application of a specially designed Expert System 'Smart Questionnaire' provides an exciting possibility to expand the scope of the study to include commercial and industrial wastes. The concept of a 'smart' questionnaire is that it adapts the questions asked according to the user's responses, thus avoiding irrelevant and confusing information. Existing in-built databases can be used for verification to determine whether the answers given are within normal bounds, and if necessary the same question can be asked in different ways as a self-checking procedure. Problems such as the units in which waste is quantified are overcome by using internal conversion factors, thus allowing the respondent to specify quantities in terms with which he/she is familiar. A further advantage is that the information is already in digital database format, alleviating the need for manual data entry with the errors this entails. The databases within the questionnaire are originally being populated using best available data from the Environment Agency's national waste survey which relates waste generation to business type and size, as well as data from other relevant sources. Business classification in the model is by means of a specially designed coding system, which could then be mapped to SIC or European waste classification codes using embedded databases.

In some cases, the results obtained using the expert system may provide a level of detail greater than that required for consideration of processing and infrastructure needs, but the database output could be tuned to provide information in the most useful format - for example, to group wastes according to the 12 master categories suggested by the Zero Waste campaign, if that is required. The aim is to overcome the limitation of data collection as a rigid and inflexible process governed by the needs perceived at the time. At the same time it is necessary to keep a balance between detail

and the practicability of gaining information, and accuracy and replicability, which can be achieved by periodic review and updating of data for tracking and predicting purposes. It is intended to improve continually both the data gathering (input) and reporting (output) of the 'smart' questionnaire using feedback from business, waste management contractors and other interested parties such as SEEDA (Southeast England Development agency) and SIEnA (Solent Industry & Environment Association).

Application of the smart questionnaire has a number of stages, the first of which is collation of existing data on C&I wastes and on the business profile in Hampshire. The data are being used to develop a sampling framework based on location, business type and key resource streams.

It should be noted that the system is currently under development, and the initial trial version presented here lacks, for example, sophisticated learning capabilities. Initially the system's learning will be confined to the update of the embedded databases, which are subsequently used to determine whether certain responses are within the normal bounds for any particular variable, and, where appropriate, how far are they from the average. Treatment of the uncertainty is also not very sophisticated, and is currently being confined to comparing of the response obtained with the normal bounds for any particular variable. However, the system is being continuously improved, and it is envisaged that the initial limitations will be duly addressed in the future.

5. RESULTS

Example 1 - Southampton glass

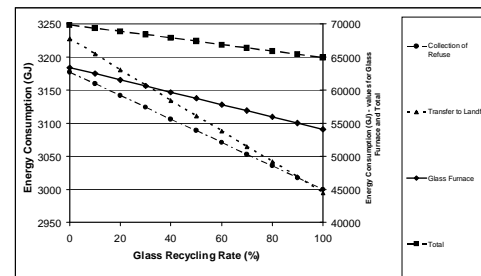


Figure 1. The dependence between the Southampton glass wastes energy footprint (major components) and the recycling rate.

By running a number of 'what if' scenarios it was found that the energy consumption related

to handling and processing Southampton glass wastes (NB: that includes manufacture of necessary yearly supply, which is included within the system boundaries) ranges between 60,000 and 70,000 GJ per year. For the current situation, the estimate of the overall yearly energy footprint was approximately 68,600 GJ. The bulk of this energy consumption is in the manufacturing process. Therefore, energy savings in manufacture achieved through the increased use of cullet [i.e. due to increased recycling] would outweigh the increased energy consumption related to the stages of collection, transportation, and processing at the processing plant [Figures 1-2].

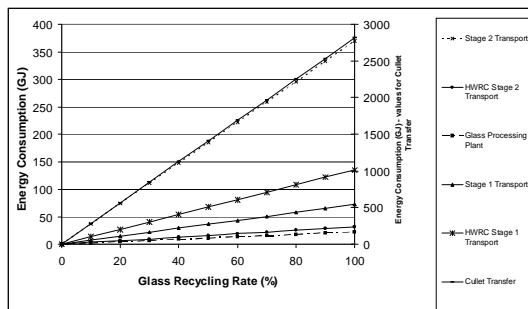


Figure 2. The dependence between the Southampton glass wastes energy footprint (secondary components) and the recycling rate.

It is worth pointing out that although within the assumptions incorporated in the model, the energy consumption per tonne of recovered material invariably decreases with an increase in the recycling rate, the rapid decrease is demonstrated only at relatively low recycling rates, after which the curve levels out [Figure 3]. This, in the author's view, provides an exciting possibility for optimizing the management decision strategies accounting for this and a multitude of other relevant factors.

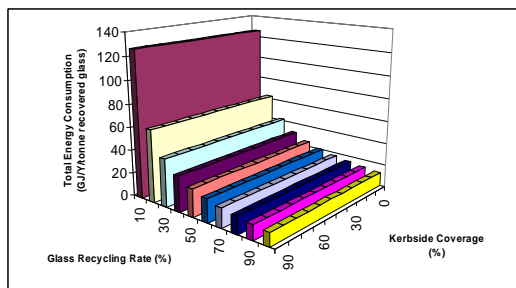


Figure 3. Energy spent per tonne of glass waste recovered.

Example 2 - Southampton paper/card

Analysis of energy footprint associated with Southampton paper wastes revealed a similar (i.e. to the glass case study) relationship between the overall energy spendings and the recycling rate [Figure 4]. As with glass, the bulk of energy consumption is in the manufacturing process, and the savings made here through increased use of recycled paper offset any increases in transport and processing energy consumed elsewhere. Our analysis have also revealed that recycling via kerbside collection has more potential (e.g. in terms of quantities collected) than via bring-sites. It should be noted, however, that in reality the exact preference to any particular option should, of course, be determined by a number of factors (i.e. in addition to the energy footprint), including, e.g., infrastructure/layout of road network, vehicle characteristics and availability, availability of human resources to run the scheme, population density, etc..

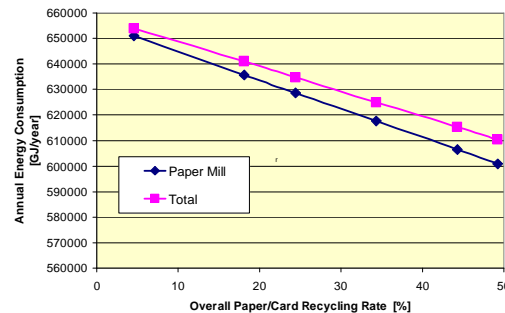


Figure 4. The dependence between the Southampton paper wastes energy footprint and the recycling rate.

6. DISCUSSION

Analysis of multicomponent systems is greatly aided by application of simulation modelling techniques (Krivtsov *et al.* 2000; Krivtsov 2001). Complex interplay among system components have previously been taken into account in a number of waste management and industrial ecology studies (Abou Najm *et al.* 2002a, b; Adamov *et al.* 1999; Bjorklund *et al.* 1999; Clift 1998; Cosmi *et al.* 2000; Korhonen *et al.* 2001; Krivtsov *et al.* 2004a). The results of the research presented here are in good agreement with the previous studies.

In general, the integration of the standard commercial and customised software has been very useful in the investigations of the energy footprint of Southampton wastes presented here. Our integrative data analysis and modelling approach included collection of a wide range of data, examination of these data

using a database, and analysis by statistical tests and simulation modelling.

The key element in the data acquisition stage of the project is the development and deployment of an expert system - 'smart' interactive questionnaire. This can later be developed into an informative and immediate feedback mechanism through which participating companies can obtain information on the best and most cost-effective ways of dealing with their waste in a particular geographical area. It is also hoped that the scheme will subsequently be expanded into a web-based tool accessible to the wider business community of Hampshire.

With some adaptation, the integrative data collection and modelling approach presented here may be applied to other types of wastes in Southampton. With further adaptation, it may also be applied to other geographical locations. Hence the research presented here may be regarded as a generic template for analysis of energy footprints associated with processing of wastes.

7. FURTHER WORK

The first stage of the project has involved analyses of household wastes. Currently, however, the structure of the emerging EDSS is being enhanced, which will allow us to process data on commercial and industrial wastes using an expert system 'Smart Waste Questionnaire' (described above). This is an exciting development of the research as it provides a possibility to quantify the waste streams generated by commercial, including small- and medium-sized, enterprises, which are notoriously difficult to assess.

Clearly, the success of the data collection survey is dependent upon the degree of cooperation offered by the business community: to maximise this, the survey work is being designed so that it offers real and tangible benefits to the business community. To achieve this, the 'smart' interactive questionnaire will be enhanced so that it not only allows accurate information gathering, but also gives feedback to individual businesses on how to maximise their waste management opportunities. This interactive system will ultimately be offered as a web-based tool accessible to all businesses in Hampshire, and ultimately across the South East.

It is worth pointing out that the emerging EDSS system presented here is still under development. However, the system is being continuously enhanced, and it is intended that further developments will include incorporation of spatial representation using GIS, improvements to the Expert System 'Smart Waste Questionnaire' as regards learning capabilities and uncertainty treatment, incorporation of a wider range of artificial intelligence techniques, and design of a graphical user-friendly interface to allow the system use by stakeholders and decision makers. It is also intended to address the issues of software and hardware compatibility, and to make the versions available to run on a wider range of platforms and operating systems (the current prerequisite is Windows XP).

It should also be noted that the analysis presented here relate specifically to Southampton. However, the existing software could be applied for analysis of waste management energy footprints elsewhere, although the relevant constants and pathways may have to be changed by the system analyst to reflect the local conditions. Extension of the scope of this research beyond Southampton area remains, however, subject for further work.

8. CONCLUSIONS

An integration of all the separate submodels into a comprehensive overall model has allowed us to assess the overall energy footprint related to glass and paper/card fractions of Southampton wastes. In future, we intend to use the overall model for the extensive comparative analysis of direct and indirect interactions within the industrial ecosystem studied (*sensu* Krivtsov et al., 2000; see also Krivtsov, 2001, 2002 and references therein).

The major source of energy savings from recycling may best be achieved through increased use of recycled material in the manufacturing process. With maximum recycling, energy savings of up to ~11% for both the glass and paper/card fractions are feasible. Therefore, recycled materials should be used to make more new materials, rather than for alternative purposes (e.g. glass as a replacement for aggregates).

The information gathered within the current and the next stage of the project will generate a resource map of C&I waste resources in Hampshire and will provide an opportunity to

rethink fundamentally what information is needed from waste audits and how it can best be used. The results will be used in planning the County's infrastructure needs, in identifying opportunities for new businesses to develop using the resources reclaimed from waste, and in mapping the way forward for the sustainable management of C&I waste in the UK.

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10. REFERNECES

- Abou Najm M., El-Fadel M., Ayoub G., El-Taha M. & Al-Awar F. (2002a) An optimisation model for regional integrated solid waste management I. Model formulation. *Waste Management & Research* 20: 37-45.
- Abou Najm M., El-Fadel M., Ayoub G., El-Taha M. & Al-Awar F. (2002b) An optimisation model for regional integrated solid waste management II. Model application and sensitivity analyses. *Waste Management & Research* 20: 46-54.
- Adamov E. O., Ganev I. K., Lopatkin A. V., Orlov V. V. & Smirnov V. S. (1999) Self-consistent model of nuclear power development and fuel cycle. *Atomic Energy* 86: 337-344.
- Argent R. M. (2004) Concepts, methods and applications in environmental model integration. *Environmental Modelling & Software* 19: 217.
- Bjorklund A., Dalemo M. & Sonesson U. (1999) Evaluating a municipal waste management plan using ORWARE. *Journal of Cleaner Production* 7: 271-280.
- Clift R. (1998) Engineering for the environment: The new model engineer and her role. *Process Safety and Environmental Protection* 76: 151-160.
- Cosmi C., Cuomo V., Macchiato M., Mangiamele L., Masi S. & Salvia M. (2000) Waste management modeling by MARKAL model: A case study for Basilicata Region. *Environmental Modeling & Assessment* 5: 19-27.
- Korhonen J. (2001) Industrial ecosystems - some conditions for success. *International Journal of Sustainable Development and World Ecology* 8: 29-39.
- Korhonen J., Wihersaari M. & Savolainen I. (2001) Industrial ecosystem in the Finnish forest industry: using the material and energy flow model of a forest ecosystem in a forest industry system. *Ecological Economics* 39: 145-161.
- Krivtsov V., Corliss J., Bellinger E. & Sigeo D. (2000) Indirect regulation rule for consecutive stages of ecological succession. *Ecological Modelling* 133: 73-82.
- Krivtsov V. (2001) Study of cause-and-effect relationships in the formation of biocenoses. *Russian Journal of Ecology* 32: 230-234.
- Krivtsov V., Banks C. J., Heaven S. & Dacombe P. (2003) Sustainable waste management - the energy question. *Wastes Management, Chartered Institute of Wastes Management* January 2003: 34-35.
- Krivtsov V., Wäger P. A., Dacombe P., Gilgen P. W., Heaven S., Hilty L. M. & Banks C. J. (2004a) Analysis Of Energy Footprints Associated With Recycling Of Glass And Plastic - Case Studies For Industrial Ecology. *Ecological Modelling* 174, 175-189.
- Krivtsov V., Walker S. J. J., Staines H. J., Watling R., Burt-Smith G. & Garside A. (2004b) Integrative analysis of ecological patterns in an untended temperate woodland utilising standard and customised software. *Environmental Modelling & Software* 19: 325-335.
- Liao S. H. (2003) Knowledge management technologies and applications - literature review from 1995 to 2002. *Expert Systems with Applications* 25: 155-164.
- Lukashev A. F., Droste R. L. & Warith M. A. (2001) Review of Expert System (ES), Geographic Information System (GIS), Decision Support System (DSS), and their applications in landfill design and management. *Waste Management & Research* 19: 177-185.
- Rizzoli A. E. & Young W. J. (1997) Delivering environmental decision support systems: software tools and techniques. *Environmental Modelling & Software* 12: 237-249.