Resources, Conservation and Recycling 53 (2009) 639–644

Contents lists available at ScienceDirect

Resources, Conservation and Recycling

journal homepage: www.elsevier.com/locate/resconrec

Towards greening a university campus: The case of the University of Maribor, Slovenia

Rebeka Lukman[a,*], Abhishek Tiwary[b], Adisa Azapagic[b]

[a] Department of Chemistry and Chemical Engineering, Laboratory for Process Systems Engineering and Sustainable Development, University of Maribor, Smetanova 17, SI-2000 Maribor, Slovenia

[b] School of Chemical Engineering and Analytical Sciences, The University of Manchester, PO Box 88, Sackville St, Manchester M60 1QD, UK

ARTICLE INFO

Article history:
Received 8 October 2008
Received in revised form 20 April 2009
Accepted 21 April 2009
Available online 23 May 2009

Keywords:
Life cycle assessment
Environmental impacts
Environmental management
Waste management
Greening universities

ABSTRACT

The environmental performance of the University of Maribor (Engineering Campus) has been assessed on a life cycle basis. The following activities have been considered in the study: the use and operation of lecture theatres (construction and maintenance, heating, lighting and water consumption) and day-to-day consumption of sundries (paper and plastic bottles). The results indicate that the heating and construction of buildings are the ‘hot spots’ in the system, for most environmental impacts. Different waste management options for the plastic and paper, including recycling, incineration and landfill, have also been compared for environmental impacts and economic costs. The option combining 70% recycling, 29% incineration and 1% landfill has been found to be most economically and environmentally sustainable.

1. Introduction

Higher education institutions (HEI) have considerable impacts on the environment as there are over 13,000 HEI worldwide (Webometrics, 2009), about one-third of which are based in Europe with a student population of over 18 million (Eurostat, 2009). HEI generate environmental impacts through both direct and indirect activities—the former include the use of classrooms, laboratories, offices and catering and the latter include commuting and consumption of food and drink at work by students and employees. Assessing the environmental impacts of universities is not a trivial task due to the complexity and diversity of their operations. Nevertheless, it is deemed important to estimate these in order to identify more sustainable options for reducing their environmental footprints. The use of a life cycle approach for these estimations is essential so as to obtain the full picture of the environmental implications of running a university. Life cycle assessment (LCA) is well suited as a tool for these purposes, as it can help quantify the materials and energy used as well as the emissions and wastes produced in the life cycle of university-related activities.

Although LCA has been used extensively for product and process analysis, its use for assessing environmental performance in the service sector, especially higher education, is relatively recent. Examples of such applications include assessing the life cycle impact of an internet infrastructure at a university (Loerincik, 2003), new university buildings (Scheuer, 2003), and printed books and e-book reading devices (Kozak, 2003). A recently proposed sustainable university model (Velazquez et al., 2006) provides a structured framework for visualising and achieving a sustainable university system by benchmarking the best practices used by 80 universities worldwide. However, to our knowledge, no study has so far addressed the impacts from everyday university activities alongside its infrastructure impacts.

In an attempt to contribute towards a better understanding of environmental impacts of HEI, this paper presents the results of an LCA study of University of Maribor in Slovenia. Due to limited data availability, the LCA study has been carried out only for the engineering departments. According to Lozano (2006), a university consists of five areas of activity: education, research, operations, outreach, and assessment and reporting. The first part of this study focuses mainly on operations and includes environmental impacts associated with the construction and maintenance of lecture rooms, heating, lighting (including other electricity consumption), and water consumption. The second part considers day-to-day sundries consumption, including the use of plastics (PET bottles used by staff and students on campus) and printing paper. Different end-of-life waste management options for the plastic and paper wastes are also considered, including recycling, incineration and landfilling.

* Corresponding author. Tel.: +386 2 2294 455; fax: +386 2 2527 744.
E-mail address: rebeka.lukman@uni-mb.si (R. Lukman).

0921-3449/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.resconrec.2009.04.014

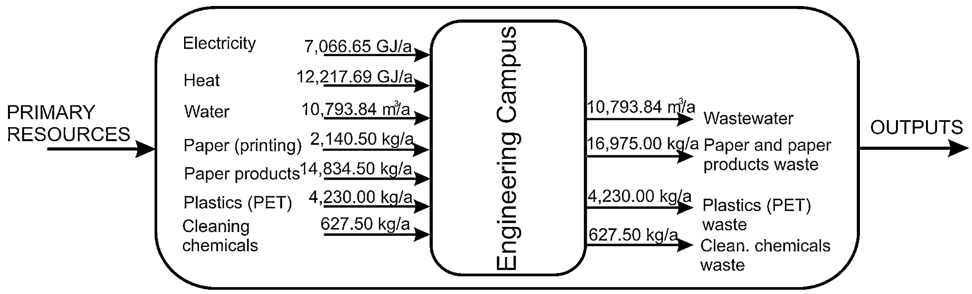

Fig. 1. System boundary for the LCA study of the Faculty of Engineering ("Engineering Campus").

2. Methods

The LCA methodology used for estimating the environmental impacts is based on the ISO 14040 and 14044 series (ISO, 1997, 1998, 2000a,b, 2006). The study has been performed using the LCA software package GaBi® (PE International, 2006) and Ecoinvent database (Frishknecht et al., 2004). The objectives of the study, system boundaries and the main assumptions are described below.

2.1. Objectives of the study, the functional unit and system boundaries

The objectives of this study are twofold—first, to estimate the life cycle environmental impacts of the institution's day-to-day operations; secondly, to identify the major 'hot spots' in the system, which could be targeted for environmental improvements.

The system under consideration is the Faculty of Engineering at the University of Maribor, housing all the engineering and science departments, including Chemistry and Chemical Engineering, Civil Engineering, Mechanical and Textile Engineering, and Electrical Engineering and Computer Science.[1] The Faculty has a student population of 3800. Therefore, the functional unit is defined as "lecturing the population of 3800 students over one year".

The following activities are included in the system boundary:

- construction and demolition of buildings (assuming an 80-year life span of the buildings);
- operation (heating, lighting, water, paper and plastics (PET bottles); and
- maintenance (cleaning and painting).

Note that the operation activities consider only the lecture rooms—the use of laboratories is excluded due to the lack of data. For similar reasons, staff and student commuting has not been considered in the study. The overall material and energy consumption, as well as waste outputs for the system considered are shown in Fig. 1.

As mentioned previously, also considered are the use of paper and PET bottles as well as their different waste management options, assuming different percentage of recycling, incineration (with energy recovery) and landfill. The impacts of recycling and incineration are included in the study but the system has been credited for both recycled materials and energy recovery from incineration. In addition to the environmental impacts, the study considers the costs of collection, transport, sorting, packaging, etc. involved in different waste management options.

As shown in Table 1, the following six waste management scenarios for paper and PET bottles are considered:

- scenarios A–C consider only one waste management option at a time, i.e. 100% landfill (A), 100% incineration with energy recovery (B), and 100% recycling (C);
- scenarios D and E consider different percentage of materials incinerated, landfilled and recycled; and
- scenario F represents the current waste management practice in Slovenia, whereby 96% of waste from the education sector is landfilled, 3% is incinerated, and the remaining 1% is disposed of in an unspecified manner (Slovenian Statistical Office, 2006). In this study, the latter is assumed to be recycling.

2.2. Data sources

The primary data have been provided by the Faculty of Engineering and other organisations, as described below:

- the information on the costs of consumables such as printing paper and for utilities such as water, electricity, and heating has been obtained from the Accounts Office; these data have been used to calculate the consumption of energy and materials in the system;
- the amount and the types of chemicals used for cleaning purposes have been provided by the Estates;
- the information on the amount of wastes produced on the campus as well as the costs of waste disposal has been provided by Snaga Ltd., the local waste management company; and
- the costs for waste recycling have been supplied by Slopak Ltd. and Dinos Ltd.

Further data have been obtained by direct measurements of the size of the lecture rooms and radiators, and by recording the total number of lights and the bulb wattage. The secondary (LCA) data have been sourced from the Ecoinvent database.

2.3. Main assumptions

The following are the main assumptions used in the LCA model:

- *Construction and demolition of buildings*. There are 6 buildings on the campus with 40 lecture rooms and they have all been considered in the study. Their life time is assumed to be 80 years. Concrete and steel used for the construction of the buildings, the

Table 1
Scenarios considered for management of waste paper and plastic (PET bottles).

Scenarios	Landfilling	Incineration	Recycling
A	100%	–	–
B	–	100%	–
C	–	–	100%
D	80%	20%	–
E	60%	20%	20%
F	96%	3%	1%

[1] The University also has several other Faculties, such as Faculty of Economics and Business, Faculty of Law, Faculty of Humanities, Faculty of Medicine, etc. which are situated elsewhere in Maribor; these are not considered in this study.

use of PVC and glass for the manufacture of windows, as well as wood for the construction of the floors, are included in the system boundary. For simplicity, the expected life time of the windows and the floorings is assumed to be same as that of the buildings (up to 80 years); however, it is recognised that this is an over-simplification as the windows (glass) would probably be changed at least once during the life time of the buildings. It has been assumed that waste concrete from the demolition of the buildings is landfilled whereas the remaining materials are recycled. The LCA impacts of different materials used for construction have been calculated using the Ecoinvent database.

- *Cleaning*. Chemicals used for cleaning the floors, windows, and other areas (such as tables, chairs, etc.) have been accounted for in the model. Information on the compositions of chemicals has been obtained from the producer web pages (Johnson Diversey, 2009). Components making up less than 5% of the cleaning chemicals, such as perfumes, limonene, and other fragrances are excluded from the assessment. The LCA data for the production of chemicals have been sourced from the Ecoinvent database.
- *Heating*. It has been assumed that each lecture hall has on average four radiators, which are operated for 150 days per year. The number of heating days represents the average heating season in Slovenia during the winter months, excluding the weekends. Heat is supplied by natural gas; the LCA data for gas have been obtained from the Ecoinvent database.
- *Lighting*. LCA of lighting relies on certain assumption such as: 7 fluorescent lights per lecture room, making a total of 280. Furthermore, the annual consumption of electricity for lighting has been estimated taking into account the variations in daylight hours in Central Europe. In addition, the consumption of electricity by 40 overhead projectors has been estimated. The LCA data for electricity generation in Slovenia have been taken from the Ecoinvent database.
- *Painting*. It has been assumed that the lecture rooms are painted every 5 years, requiring 960 kg of paint. The LCA data for the paints have been sourced from the Ecoinvent database, based on the paint specification provided by the manufacturer (Helios, 2007).
- *Materials*. Only the use of PET (bottles for water and soft drinks) and paper have been considered.
- *Waste management*. The assumptions and LCA impacts for landfilling, recycling and incineration with energy recovery are based on those used in GaBi®. It has also been assumed that PET is recycled mechanically, for which the system gas has been credited.

Road transport is assumed to be the major means for the delivery of sundries to and removal of wastes from the university. Peripheral activities, such as installation processes for lighting and heating equipments, as well as procurement of supplementary products, such as mops for cleaning and equipment for painting, are not included in this assessment due to the lack of data.

3. LCA results

3.1. Overall environmental impacts and hot spots

The environmental impacts have been calculated following the CML2001 impact assessment method (Guinée, 2002). The LCA results shown in Figs. 2 and 3 indicate that the most significant impacts from the system are acidification potential (AP), global warming potential (GWP), human toxicity potential (HTP) and terrestrial eco-toxicity potential (TETP). The 'hot spots' in the system, contributing to most impacts are heating and construction of the buildings (see Fig. 4). Heating has the largest contribution to ADP, AP, GWP, ozone layer depletion potential (ODP) and photochemical ozone creation potential (POCP). The construction of buildings is the largest contributor to human toxicity potential (HTP) and terrestrial eco-toxicity potential (TETP). Paper products contribute to the eutrophication potential (EP), GWP, HTP, ODP and TETP, the lighting contributes mainly to ODP and POCP, while other activities, such as cleaning and water consumption, have smaller contributions.

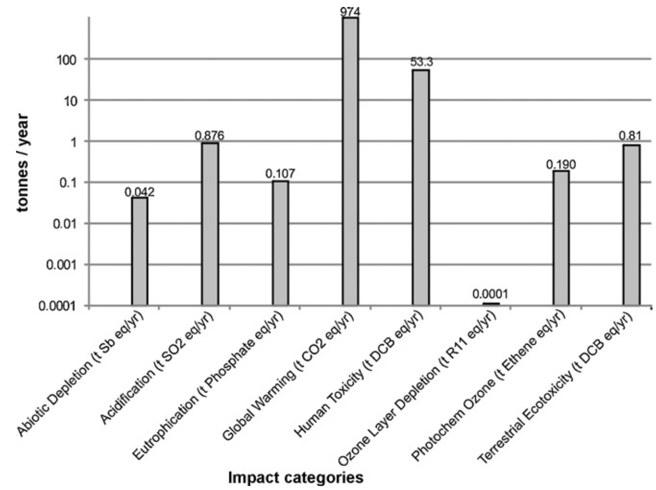

Fig. 2. Environmental impacts of the Faculty of Engineering.

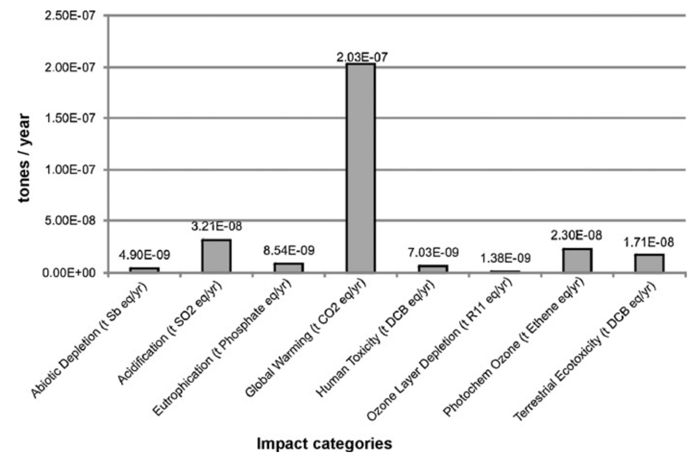

Fig. 3. Normalised environmental impacts from the Faculty of Engineering.

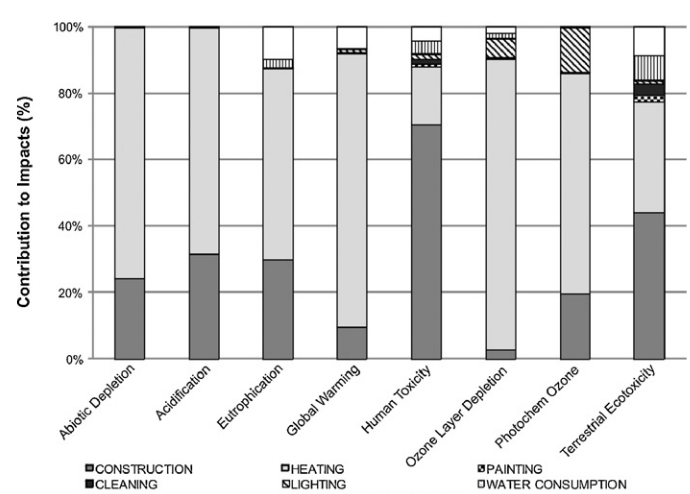

Fig. 4. Relative contribution of different activities to the total environmental impacts.

Table 2
Emissions to air (tonnes/year).

Burdens	Construction	Heating	Painting	Lighting	Cleaning
SO_2	6.57×10^{-1}	3.22×10^{-1}	1.94×10^{-3}	2.53×10^{-3}	1.05×10^{-7}
NO_x	6.76×10^{-1}	5.07×10^{-1}	1.04×10^{-3}	1.65×10^{-3}	3.56×10^{-7}
CO_2	2.04×10^{2}	8.13×10^{2}	2.49×10^{-8}	1.66×10^{-5}	3.91×10^{-6}
VOC	5.70×10^{-1}	2.37	1.30×10^{-4}	1.82×10^{-4}	5.32×10^{-4}
Particles	6.35×10^{-1}	3.72×10^{-2}	5.05×10^{-3}	1.64×10^{-4}	4.90×10^{-4}

Table 3
Emissions to water (tonnes/year).

Burdens	Construction	Heating	Painting	Lighting	Cleaning
Chloride	3.03	1.37	1.22×10^{-2}	3.05×10^{-2}	4.41×10^{-3}
Cyanide	9.80×10^{-4}	1.54×10^{-4}	7.64×10^{-3}	2.50×10^{-8}	2.06×10^{-5}
Nitrates	5.49×10^{-5}	2.31×10^{-4}	7.58×10^{-5}	4.29×10^{-9}	1.18×10^{-9}
Phosphorus	2.13×10^{-4}	5.77×10^{-6}	3.88×10^{-8}	5.13×10^{-11}	3.71×10^{-7}
Sulphates	3.44×10^{-1}	2.67×10^{-5}	3.39×10^{-4}	4.33×10^{-3}	6.21×10^{-4}
Organic emissions	8.47×10^{-3}	1.08×10^{-3}	1.68×10^{-5}	6.80×10^{-6}	6.20×10^{-12}

Tables 2 and 3 provide a list of selected emissions to air and water from various life cycle stages. The selection of these emissions is based on the substances referred to in the ordinances for quality of outdoor air and fresh water (UL RS 40/01 and UL RS 52/02) and the Slovenian Law for environmental protection (UL RS 39/06). As expected, over the whole life cycles of the considered activities, heating and buildings construction contribute most to the emissions of sulphur dioxide, nitrogen oxides, carbon dioxide, volatile organic compounds and particulate matter. Similar trend is found for the releases of chlorides, phosphorous, sulphates and organic emissions to fresh water (Table 3).

3.2. Results from waste management scenario analysis

The LCA results for different waste management options are compared in Table 4. Overall, scenario C (100% recycling) has the lowest environmental impacts, followed by scenarios B (100% incineration) and E (60% landfill and 20% incineration and recycling each). Landfill only (scenario A) appears to have the highest environmental impacts overall. Therefore, compared to the current practice in Slovenia (scenario F), scenario C could provide on average a 6.2% reduction in the overall impact. However, this requires 100% recycling, which is not a practical solution in the foreseeable future.

The analysis of the individual impacts shows that scenario C has the lowest GWP (1582 t CO_2 equiv./year) and scenario F the highest (1652 t CO_2 equiv./year). Landfill only (scenario A) has the highest AP (12.97 t SO_2 equiv./year), whereas incineration only (scenario B) has the lowest (8.6 t/year). The results reveal that opting for incineration only would lower AP from the current practice (scenario F) by around 33%. ADP and POCP are comparable for all waste management options at 3.44 t Sb equiv./year and 0.52 t ethene equiv./year, respectively. The analysis also suggests that adopting the recycling only option (scenario C) would lead to a reduction in TETP of up to 5% from the current 1.588 t DCB equiv./year for the F option; all other options are comparable to the current situation. In the case of EP, however, all options would lead to a reduction compared to the current practice, with the largest reduction achieved by adopting scenario C (10% reduction) or B (7% reduction). Scenario C would also reduce ODP by up to 2% from its current levels, whereas for the remaining scenarios there would only be marginal improvement in this impact category.

4. Identifying improvement options

The 'hot-spots' analysis discussed in Section 3.1 indicates that construction, heating and lighting are the largest contributors to the environmental impacts from this system. There is little that can be done about construction of the existing buildings; however, targeting heating could potentially lead to significant environmental improvements. This is discussed below. In addition, various waste management options are analysed further to investigate at what cost the environmental improvements discussed in Section 3.2 could be achieved.

4.1. Alternative heating means

Several modifications to the current heating system have been explored and these include substitution of natural gas with renewable sources, such as wood pellets, solar energy, and a combination of both. The LCA results of these proposed modifications are presented in Table 5; note that only the results for GWP are shown as this is the impact that heating contributes to most. The results would suggest that, compared to the conventional gas heating system, a combined wood and solar heating would reduce GWP by 82%. This alternative is a feasible proposition since Slovenia has large forested areas and receives adequate sunshine for a substantial part of the year.

Table 4
Environmental impacts of different waste management scenario for paper and plastics (tonnes/year).

Impact category	Waste management scenarios					
	A	B	C	D	E	F
Acidification potential [t SO_2-equiv.]	12.970	8.594	10.029	12.095	11.506	12.809
Abiotic depletion potential [t Sb-equivalent]	3.438	3.436	3.440	3.437	3.438	3.438
Eutrophication potential [t phosphate-equiv.]	0.435	0.403	0.391	0.428	0.419	0.434
Global warming potential 100 years [t CO_2-equiv.]	1653.08	1651.94	1582.02	1652.84	1628.64	1652.33
Ozone depletion potential [t R11-equiv.]	9.524	9.475	9.345	9.514	9.478	9.520
Photochemical ozone creation potential [t ethene-equiv.]	0.527	0.517	0.520	0.525	0.523	0.526
Terrestrial eco-toxicity potential [t DCB-equiv.]	1.590	1.570	1.511	1.586	1.570	1.588

Table 5
Global warming potential for different heating options.

	GWP 100 years [t CO_2 equiv./year]
Heating, gas	8.63×10^2
Heating, wood	1.61×10^3
Heating, wood and solar	1.54×10^2

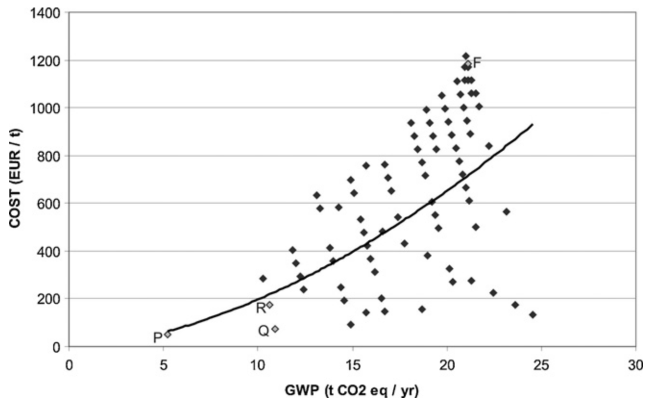

Fig. 5. Global warming potential (GWP) versus costs for paper waste management.

4.2. Optimising waste management

This part of the study has involved comparison of different waste management options from both environmental and economic perspectives, in an attempt to reduce the environmental impacts as well as economic costs of waste disposal. The latter is particularly important as the annual cost of managing waste in the Faculty of Engineering is around 145,000 Euros. For these purposes, 162 different waste management scenarios – representing differing combinations of recycling, incineration and landfill for paper and plastic wastes – have been assessed. The results have been analysed for GWP and the economic cost associated with each waste management option.

As shown in Figs. 5 and 6 for paper and plastic wastes, respectively, scenario P (99% recycling and 1% incineration) has the lowest GWP. Compared to the current waste management practice in Maribor (scenario F) this represents a reduction in GWP of up to 16.51 t CO_2 equiv./year. Based on our model assumptions, this scenario is estimated to have the lowest costs and would save up to 24,000 Euros per year in waste management costs in the Faculty of Engineering.

However, this option is not practical since most countries recycle only up to 30% of municipal waste; the exceptions to this are Austria and the Netherlands, which recycle 60% or more (The Economist, 2007). Taking the latter two countries as a model, scenario Q in Fig. 5 considers 70% recycling, 29% incineration and 1% landfilling of paper—while the costs remain the same as in scenario P, the GWP is twice as high compared to P. Scenario R, which considers 70% recycling, 20% incineration and 10% landfill, achieves GWP similar to scenario Q but at a much higher cost. Similar trends are noticed for PET waste management options shown in Fig. 6.

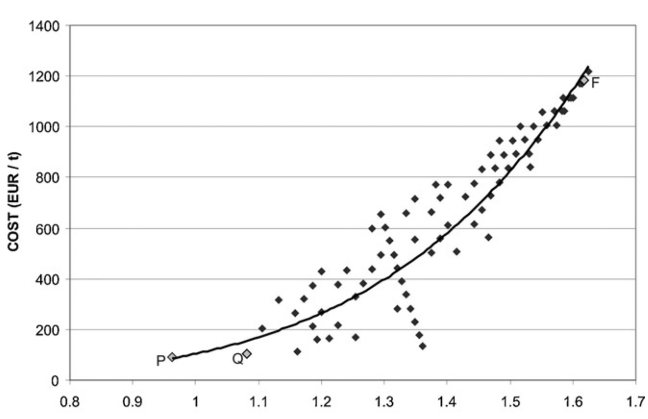

Fig. 6. Global warming potential (GWP) versus cost for plastics waste management.

5. Conclusions

This paper has evaluated the environmental performance of the Faculty of Engineering at the University of Maribor, Slovenia, using a life cycle approach. The results suggest that the most significant environmental impacts from the operation of the university are global warming, acidification, human toxicity and terrestrial eco-toxicity. The main contributors to the impacts are heating and construction and demolition of buildings. In order to reduce the environmental impacts – especially global warming – various heating improvement options have been considered. Replacing the conventional gas-fired boiler with a combined wood and solar heating system is estimated to reduce GWP by up to 82%. In the long run, these improvements could benefit the university (including the broader region) not only from an environmental perspective but also in many other ways—such as reducing the operational costs, earning green credentials through fostering an environmentally responsible management practice, and promoting sustainable development.

Various waste management scenarios for paper and plastic, and their impacts on environment have also been considered. The current waste management practice at the educational institutions in Slovenia is to landfill 96% of waste. This is causing various environmental impacts, most notably global warming. Our results suggest that a combination of 70% recycling, 29% incineration and 1% landfill could reduce global warming potential by 47% compared to the current waste management practice, and that this could be achieved at an affordable cost.

Thus, this case study demonstrates that there is a significant potential for improving the environmental performance and reducing the costs of the university operations. These improvements could also influence other parts of the university system—most importantly education ("teach what they preach"), research (learning laboratories) as well as community outreach (disseminating best practices to both the public and other public institutions).

Acknowledgement

One of the authors (RL) would like to thank the Slovenian Research Agency for financing this research within the Young Researcher Programme and *Ad Futura* – Science and Education Foundation of Republic Slovenia (Public Fund) – for supporting her research visit to the School of Chemical Engineering and Analytical Sciences at The University of Manchester, U.K. The author is also grateful to the University of Manchester for hosting her visit. She would also like to thank Prof. Peter Glavič for his comments on the manuscript.

References

Eurostat. Education and training. Students—tertiary education. http://epp.eurostat.ec.europa.eu/portal/page?_pageid=1996,39140985&_dad=portal&_schema=PORTAL&screen=detailref&language=en&product=REF_TB_education_training&root=REF_TB_education_training/t_edtr/t_educ_indic/tps00062; 2009.
Frishknecht R, Jungbluth N, Althaus HJ, Doka G, Dones R, Hellweg S, et al. Ecoinvent Data v1.1, Ecoinvent Centre, Swiss Centre for life cycle Inventories. Switzerland: Dubendorf; 2004.

Guinée JB. Handbook on life cycle assessment: operational guide to the ISO standards. Dordrecht, The Netherlands: Kluwer Academic Publisher; 2002.
Helios. Available online (December 2007): http://www.helios.si; 2007.
ISO. Environmental management – life cycle assessment – principles and framework, ISO 14040. Geneva: International Organization for Standardization; 1997.
ISO. Environmental management – life cycle assessment – goal and scope definition and inventory analysis, ISO 14041. Geneva: International Organization for Standardization; 1998.
ISO. Environmental management – life cycle assessment – life cycle impact assessment, ISO 14042. Geneva: International Organization for Standardization; 2000a.
ISO. Environmental management – life cycle assessment – life cycle interpretation, ISO 14043. Geneva: International Organization for Standardization; 2000b.
ISO. Environmental management – life cycle assessment – requirements and guidelines, ISO 14044. Geneva: International Organisation for Standardisation; 2006.
Johnson Diversey. Products and services, products fact sheets. Available online (February 2009): http://www.johnsondiversey.com/Cultures/en-GB/OpCo/Products+and+Systems/; 2009.
Kozak GL. Printed scholarly books and e-book reading devices: a comparative life cycle assessment of two book options, conference record. In: 2003 IEEE international symposium on electronics and the environment; 2003. p. 291–6.
Loerincik Y. Life cycle environmental impact of the internet infrastructure in a university. In: IEEE international symposium on electronics and the environment; 2003. p. 173–6.
Lozano R. Incorporation and institutionalization of SD into universities: breaking through barriers to change. Journal of Cleaner Production 2006;14(9–11):787–96.
PE International. http://www.gabi-software.com/; 2006.
Scheuer C. Life cycle energy and environmental performance of a new university building: modeling challenges and design implications. Energy Buildings 2003;35(10):1049–64.
Statistical Office of Republic of Slovenia. Waste treatment. Available online: http://www.stat.si (December 2006) 2006a [in Slovene].
Statistical Office of Republic of Slovenia. Annual energy statistics, Slovenia. Available online: http://www.stat.si (December 2007) 2006b [in Slovene].
The Economist. The truth about recycling. Econ Technol Q 2007;383(8541): 20–3.
Velazquez L, Munguia N, Platt A, Taddei J. Sustainable university: what can be the matter? J Cleaner Prod 2006;14(9–11):810–9.
Webometrics. Catalogue of World Universities. Available online: http://www.webometrics.com (February 2009); 2009.