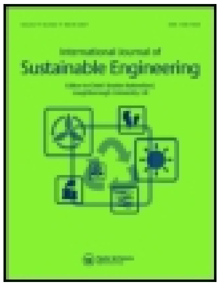

International Journal of Sustainable Engineering
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tsue20

An environmental sustainability analysis in the printing sector

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Version of record first published: 09 Aug 2012.

International Journal of Sustainable Engineering
2012, iFirst article, 1–10

Taylor & Francis
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(*Received 30 January 2012; final version received 14 June 2012*)

Information and communication technology tools could currently contribute to support firms in increasing the environmental sustainability of their production processes: the capability to monitor data on environmental performance is a key feature. This study proposes a decision support system for estimating and assessing the environmental performance of a specific printing product. Environmental sustainability concepts are just being applied in the printing sector: a critical analysis has highlighted that environmental eco-labelling schemes are widespread for raw materials; a few of interest have been addressed by researchers and practitioners to final products. The approach proposed aims to collect and merge environmental features of raw materials with data about printing processes carried out directly by the firm. Thus, the model allows a fast but integrated assessment of the whole environmental sustainability level of a specific printing product. With this, an overall sustainability assessment could be supplied to the final customer and to firm managers by integrating economic and environmental information in a common decision system. A prototypal software tool has been developed based on the approach proposed: the tool could be applied in the design as well as in the control phase for supporting scenario analyses to improve the environmental sustainability level of such a product.

Keywords: environmental sustainability; printing sector; life cycle; eco-labelling

1. Introduction

Green supply chain strategies are widespread in several mass production sectors from process industries to discrete part manufacturing. One well-known approach is the so-called ‘carbon footprint’ which aims to measure in a quick way the environmental impact of such activity across the whole supply chain (Laurent *et al.* 2010, Sundarakani *et al.* 2010, Pandey *et al.* 2011). This approach has also been applied in the public sector for assessing environmental performance in a regional scale (Bing *et al.* 2011). One critical issue of the carbon footprint approach is that it focuses only on one environmental impact category, i.e. effects due to CO_2 generation. However, quantitative models could also be applied: Life Cycle Assesment (LCA) technique represents one of the most representative approaches for environmental sustainability estimation (Halog 2004). As a quantitative tool, it usually requires a higher resource effort mainly due to the availability of a huge quantity of data. Environmental management tools based on different approaches have been developed in several industrial sectors: Finnveden and Mobergc (2005) propose a critical review about the most widespread approaches. Two recent studies have focused on this issue: Wong *et al.* (2010) proposed a classification based on the analysis technique (e.g. matrices and checklists). Ahlroth *et al.* (2011) focused their analysis on how modelling effective weighting actions is applied to impact categories in environmental management systems. The recent fast-growing development of efficient information and communication technology (ICT) tools is contributing to support firms in assessing and controlling their own environmental sustainability levels. One key feature is that ICT tools have the capability to monitor, measure and manage data about environmental performance of such a product. Several recent examples are showing this potentiality in different phases of product life cycle. By referring to the consumer communication phase, Nike had developed in 2010 a web-based tool called ‘Nike Environmental design tool’ for supporting consumers to measure impacts related to materials applied in their clothing products.

By focusing on the printing sector, environmental sustainability concepts are quite new approaches. Montero *et al.* (2010) proposed a strategic set of metrics designed for the printing industry in order to measure, track and integrate sustainability concepts into their business practices. Ghorbannezhad *et al.* (2011) proposed a reference model for applying effectively the Cleaner Production approach in a paper and pulp firm.

Recently, a network of non-profit organisations (Environmental Paper Network 2011) focusing on sustainability issues in North America pulp and paper industries have proposed the so-called ‘Paper Calculator’, a software tool which supplies a simplified web-based model for assessing environmental impacts of different types of papers. A similar tool has also been developed by

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ISSN 1939-7038 print/ISSN 1939-7046 online

http://dx.doi.org/10.1080/19397038.2012.704086
http://www.tandfonline.com

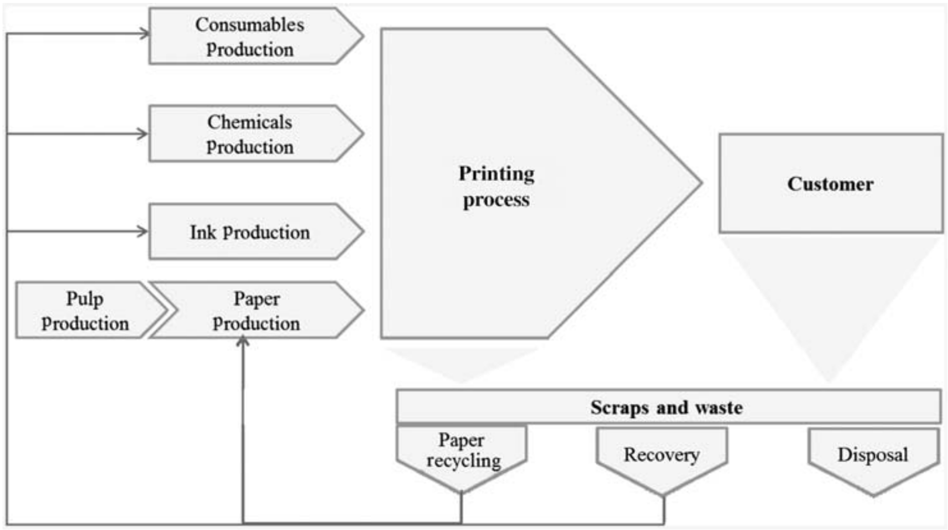

Figure 1. Main process stages in the printing supply chain.

the British Printing Industries Federation (BPIF): the so-called 'BPIF Carbon Calculator'. The tool focuses on estimating the carbon footprint of a printing activity in a simplified way. Moreover, multinational firms – such as HP and Xerox – are developing their own tools. The HP Carbon Footprint Calculator (HP 2009) is a free web-based software able to estimate energy efficiency and carbon footprint of their printing devices. The latter – called Xerox sustainability calculator (Xerox 2008) – supplies to customer environmental impact assessment of specific printing devices aiming to optimise printing product impacts.

Moreover, environmental labelling models (the so-called eco-labelling schemes) are widespread in this sector: they are focused as the previous analysed tools about raw materials in the printing supply chains. Thus, the aim of this study was to propose a decision support system for assessing the environmental sustainability of a specific printing product: the tool will manage information derived from the whole supply chain from raw material production to operational printing process activities. The proposed tool could be applied both in the planning phase by supporting scenario analysis and in the controlling phase in order to verify estimated versus actual environmental performance.

The paper has been organised into two main sections: a critical analysis about the actual application of environmental sustainability concepts in the printing supply chain is proposed in Section 2: the aim is to critically analyse the level of diffusion of environmental concepts in this supply chain. This critical review will support a more effective design of the proposed tool; the approach and the decision support system for an offset lithography printing process are discussed in detail in Section 3.

2. An analsyis of environmental sustainability concepts in the printing supply chain

One effective strategy for applying environmental sustainability concepts is the application of an eco-labelling scheme (Herrup 1999, Flores *et al.* 2008, Bratt *et al.* 2011): they briefly supply environmental information about both products and organisations. One reference model is proposed by ISO (2000); several other approaches are applied all over the world in different industries.

Environmental product certifications in the printing supply chain are currently focusing on raw material production. A printing supply chain is depicted in Figure 1. Typical input materials are consumable products (e.g. packaging materials), inks, chemicals and paper. Several types of printing processes could be carried out: the most widespread is offset lithography by which images are first transferred to a plate – usually made of metal; next, the plate is chemically treated so that only image areas (such as type, colours, shapes and other elements) will accept ink. The plate is then rolled onto a rubber cylinder applying the inked area, and the rubber cylinder applies the image to the paper. The system is defined 'offset' as the plate is not in direct contact with the paper thus preserving the quality of the plate. Recovery activities could be carried out on both plates and ink products. Moreover, paper recycling could be carried out directly from scraps of the printing process (defined as *Pre-consumer type*) and/or postponed from customer wastes (*Post-consumer* type).

Input materials determine a heavy impact on the whole environmental sustainability level which characterises the specific printing supply chain. Thus, the environmental performance of the whole supply chain could vary if raw materials are quite different: as an example, if a biological inking product is applied, sustainability level of the whole chain will be modified both at the upstream level (i.e. raw materials) and at the downstream level due to an easier waste recovery treatment.

Thus, efforts of industries are now first focusing on both developing greening raw materials and certifying the environmental performance of their products. Eco-labelling schemes are quite widespread in this sector. Furthermore, a critical analysis is proposed in order to point out both the information supplied by this environmental product certification and the level of their diffusion all over the world. This analysis will support the design of the proposed decision support system as data available for certified products will be directly acquired for assessing the whole environmental level of a specific printing product. First of all, environmental eco-labelling schemes could be classified as *mono-* or *multi-level* as they focus only on one or more than one level of the printing supply chain. Furthermore, eco-labelling scheme could focus on controlling only one criterion (*mono-criteria* scheme) or more than one in strategic point of view (*multi-criteria scheme*).

According to a mono-level certification, several schemes focus on certifying the paper recycling process. As reported previously, recycled fibres could be divided into two main categories: pre- and post-consumer type. The first type refers to materials derived from the waste stream during a manufacturing process; the second type is usually derived by private or public customers, e.g. magazines and newspapers (Canadian Standards Association 2008).

In Germany, the Federal Ministry for the Environment has defined in 2009 by a public agency (the RAL), the so-called ‘Der Blaue Engel’, for certifying products made by recycled paper (RAL 2009). This certification is awarded to companies that supply products which generate benefit to the environment and, at the same time, meet high standards of serviceability as well as health and occupational protection. Main requirements are that the paper product has to be mainly made by recycled waste paper, and a limited quantity of dangerous substances has to be applied in the pulp paper production process. Similar initiative has been launched by the Singapore Environment Council: the ‘Singapore Green Label’ award for printing paper imposes a minimum content of 50% of recycled paper fibre (SEC 2011); detailed requirements are introduced to certify a ‘recycled paper’. Recently, a private initiative has been launched also in the UK by the National Association of Paper Merchants (NAPM 2011): they have introduced the so-called ‘NAPM Recycled Paper Marks’, in order to certify paper and board products produced by genuine recovered fibres. The US Environmental Protection Agency (EPA) defines ‘recycled’ as a paper if it contains 100% post-consumer recovered fibre; if the post-consumer content is less than 100%, the paper should be defined as ‘recycled-content’ paper (EPA 1996).

Furthermore, another category focuses on certifying the use of primary fibre (i.e. virgin fibre) in the pulp production process: the aim is to supply information to the customer (intermediate or final) about raw materials production. The most well known is the Forest Stewardship Council (FSC) certification: it is a non-profit organisation established to promote the responsible management of the world’s forests. It focuses on spreading procedures for a more responsible and sustainable forest management worldwide: their system works throughout the entire forest supply chain to promote good practice aiming to certify the respect of ecological, social and ethical standards.

Furthermore, several environmental schemes are mono-level and mono-criteria: they focus on one level of the printing supply chain by assessing only one critical parameter (i.e. criterion). They usually refer to paper production process by certifying the absence or a limited use of chemicals. One example is the so-called ‘Long Life label’, an ISO standard (ISO 1994) that specifies the requirements about paper for special applications, such as for document archiving. The standard defines minimum requirements in terms of strength, content of substance that neutralises acid action and so on. By analysing the upstream process in the printing supply chain (i.e. the pulp production), two main schemes could be outlined: the elemental chlorine free (ECF) and the total chlorine free (TCF) labels. The first identifies paper bleached with a chlorine derivative (i.e without elemental chlorine); the latter certifies pulp production process by which bleaching activities are carried out without any type of chlorine derivative or that has not been bleached at all (Solomon *et al.* 1993). Furthermore, the ‘optical brightener additives free’ (defined as ‘OBA free’) label identifies the absence of chemical additives widely used in paper coatings to increase the quality of the final product during the printing process phase.

Finally, by a multi-criteria point of view, a specific directive defines the ECOLABEL certification (EU, 2009; EU, 2011) in the European Union: it points out criteria for a voluntary environmental certification for copying and graphic paper. It also fosters to improve environmental performance in a life cycle way starting from raw materials – e.g. by promoting the application of special recycled fibres in manufacturing processes – and in the process phases, e.g. by supporting the reduction of sulphur and CO_2 emissions. Furthermore, an eco-labelling scheme has been fully applied since 2003 in the European Nordic areas: it is called the NORDIC ECOLABEL or SWAN (Nordic Ecolabeling 2003). It is a multi-criteria and multi-level certification as it defines requirements for pulp and paper production and also for specific final products (e.g. tissue products).

Table 1. Synthesis of the proposed classification of environmental eco-labelling schemes in the printing sector.

	Supply chain		Production process	
Environmental scheme	One level	Multi-level	Mono-criteria	Multi-criteria
The European Ecolabel		X		X
The Nordic Ecolabel – the Swan		X		X
Singapore Green Label	X			X
Der Blaue Engel	X			X
NAPM recycled	X			X
FSC	X			X
Long Life label (ISO 9706)		X		X
ECF/TCF	X		X	
OBA free	X			X

A synthesis of the proposed critical analysis is given in Table 1.

In conclusion, the critical analysis has outlined different issues which are briefly discussed as follows:

- concepts of environmental sustainability are yet applied in the printing supply chain as several initiatives are being carried out all over the world;
- current initiatives are mainly focused on one specific level of the supply chain as multi-level schemes are not usually applied in this sector;
- an integration between strategic (e.g. the definition of more green product features) and operational levels (e.g. the design of common metrics for assessing environmental impacts) is not yet fully applied in this supply chain.

Furthermore, certified products are characterised by a high information value as data on environmental impacts due to their production are well known. The aim of the proposed approach is to integrate in a simplified but effective way information about raw materials with that derived directly from the printing processes in order to 'certify' each single printing product along its whole life cycle. The proposed approach is detailed in Section 3.

3. The proposed approach

The proposed method aims to estimate by an index analysis sustainability level an offset lithography printing product; this technology process is usually applied in large-scale plants for producing high-volumes and high-quality printed products. The rationale of the model is proposed in the following paragraph.

3.1 Rationale

As defined in Section 2, environmental product certifications in the printing sector mainly supply knowledge about a single level of the printing supply chain. Few projects have focused on the production process. Recently, Hermann *et al.* (2007) have developed a decision support system aiming to provide information on the overall environmental impact of a plant pulp based on the integration of life cycle assessment, multi-criteria analysis and environmental performance indicators. It focuses only on one level of the printing supply chain.

The main purpose of the proposed model is to supply information about environmental impacts associated with a print product by collecting data derived both from input material production and from specific printing processes. The integration of the two levels could improve the overall efficiency of the firm as the system allows to point out process stages which are critical according to both economic and environmental points of view (Da Silva and Amaral 2009). Furthermore, the model could also support producers of printed items in the design and planning phases by comparing more environmental sustainable solutions for raw material (i.e. supplier selection) and equipment selections. The proposed framework is depicted in Figure 2.

First of all, input information concerns environmental features of raw materials, production orders (e.g. quantity, delivery date and paper type) and resources (i.e. in terms of process equipment) consumption. The proposed framework integrates several types of environmental data: primary data, obtained directly from operational field, and secondary data, which could be derived by specific databases. Otherwise, information derived from literature has to be applied for characterising the environmental sustainability of raw materials.

Next, a set of environmental indicators was developed in order to characterise the sustainability level of the final printed product: impact categories were obtained by the well-known ISO 14001 standard (2007). Thus, model outputs supply the assessment of the whole environmental sustainability level of a printed product made by an offset lithography printing process, by involving data from raw material production to manufacturing processes. Transportation activity of both raw materials and final products was not introduced in this model.

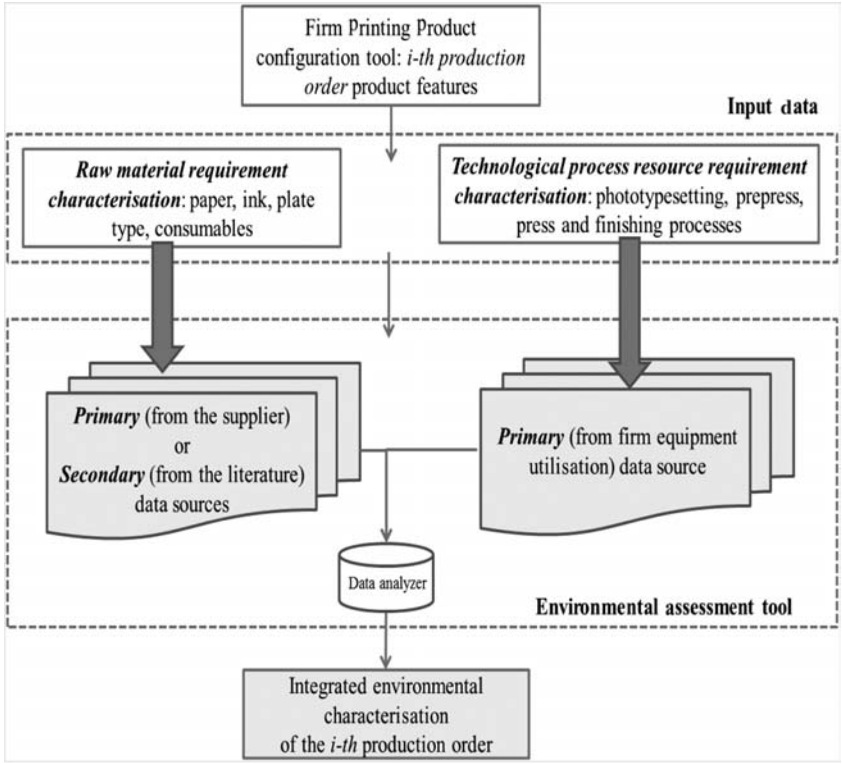

Figure 2. The general framework of the proposed decision support systems.

3.2 Model description

A brief description of common activities usually carried out in the printing process is proposed. By excluding concept visualisation and creative activities, the first process activity usually involves the layout optimisation in which the design is integrated to technological burdens due to paper size and process equipment. During this step, raw material selection and production time estimation are also carried out by a software configuration tool allowing estimating costs. After order acceptance by the customer, the firm plans its activities according to delivery dates and resource availability. Usually, production process consists of the following:

- *Prepress:* it involves all activities from stripping pages to preparing printing plates by a photomechanical exposure and processing of light-sensitive emulsion.
- *Printing*: it mainly consists in setting the printing plates, adjusting the ink and then setting paper sheets before starting the printing processes. Used papers usually become wastes.
- *Finishing and binding steps*: it involves all final activities such as cutting, trimming and adhesive binding.

Thus, the proposed sustainability analysis tool starts working in the design phase as information about the type of raw material is required as depicted in Figure 3. As defined in the previous paragraph, data on raw materials could be derived from a primary source (i.e. the supplier which has applied an eco-labelling scheme) or from a secondary source (e.g. scientific studies and databases). Primary data source represents direct observation and measurement of environmental impact of an activity. Thus, the importance of application of an eco-labelling certification will increase the reliability of estimated outputs. Secondary data refer to generic materials, and consequently resource applied for its production (e.g. in terms of energy, transport and wastes); they are usually available in the scientific literature as they are background data usually originated by academic, private or government studies.

Examples are the EcoInvent database supplied by the Swiss Centre for Life Cycle Inventories, the US Life Cycle Inventory database supplied by the National Renewable Energy Laboratory; other tools have been developed by the American Forest and Paper Association, by the US EPA's Landfill Methane Outreach Program (LMOP). Interesting information on best available techniques defined for the pulp and paper industry could also be derived from the IPPC Reference Document (EU 2001).

Therefore, at the end of the design phase, the printing firm could integrate traditional cost estimation analysis with a first estimation of environmental impacts due to a specific production order. A scenario analysis (e.g. about

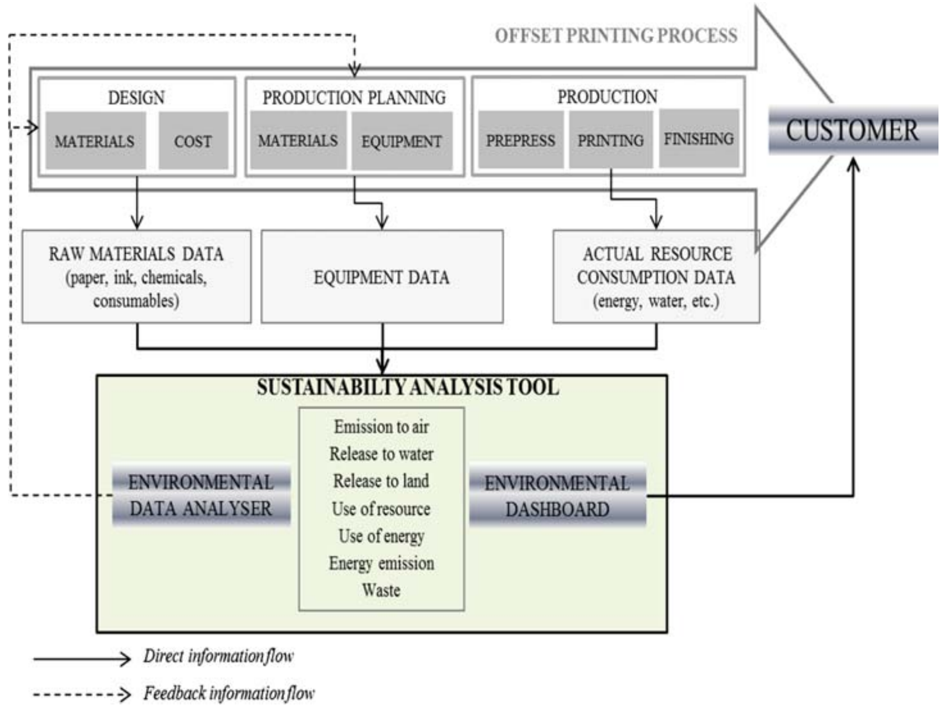

Figure 3. The model workflow.

different paper suppliers or ink producers) could be easily carried out aiming to define more sustainable strategies. As sustainability concepts are applied starting from an early stage of the whole printing process, it could contribute to reduce in an effective way environmental pressures of such a production.

Next, if a production order is confirmed, the planning activity is carried out: order scheduling supplies to the proposed model information about resource types and their estimated utilisation level (e.g. length of cycle times). Thus, the total estimated environmental sustainability level due to a specific production order (i.e. a printed product) is estimated based on specific impact categories derived from the ISO 14001 standard: emissions to air, releases to water, use of resource and energy and waste. Data are available through the so-called ‘environmental dashboard’ module and were estimated by the ‘environmental data analyser’. Finally, after manufacturing processes were carried out, data on equipment utilisation were acquired directly by a dynamic communication protocol. Thus, a comparison between estimated and actual environmental sustainability level of the printed products is available through the ‘environmental dashboard’ module.

The operational structure of the ‘environmental data analyser’ module is described in Figure 4: environmental data are available for each possible alternative evaluated in the design step aiming to configure a production order; therefore, input data (such as order quantity) are matched with environmental features characterising each material in the bill of materials; primary data source could be added if a certified supplier is available; otherwise, a secondary source could be estimated. The proposed model includes management of data archives (database), concerning primary and secondary data, linked with selection procedures to permit environmental assessment calculation.

Three main activities have to be carried out. At first, the *material (and supplier) selection phase* has to be carried out: all raw materials, consumables and production tools requested for the specific production order have to be added. As defined in Figure 2, production order in the printing sector is usually defined in the design step by specific software tools: information communicated to the prototype regards raw material requirement, production order quantities and technical features about technological processes. Thus, raw materials characterisation by an environmental point of view has to be defined. The proposed prototype system allows to add data in two ways: if a primary data source is available, data have to be added manually as the specific raw material (e.g. the paper) is ‘certified’, i.e. an eco-labelling scheme is applied. Otherwise, environmental data are directly linked by the module as they were introduced from specific databases (secondary data source). As an example, data on several paper types by an environmental point of view were introduced in the paper database which supplies information to sustainability assessment module. Data were introduced according to a reference unit (e.g. $kg_{eq}CO_2$ per kg of paper); estimated global impacts in

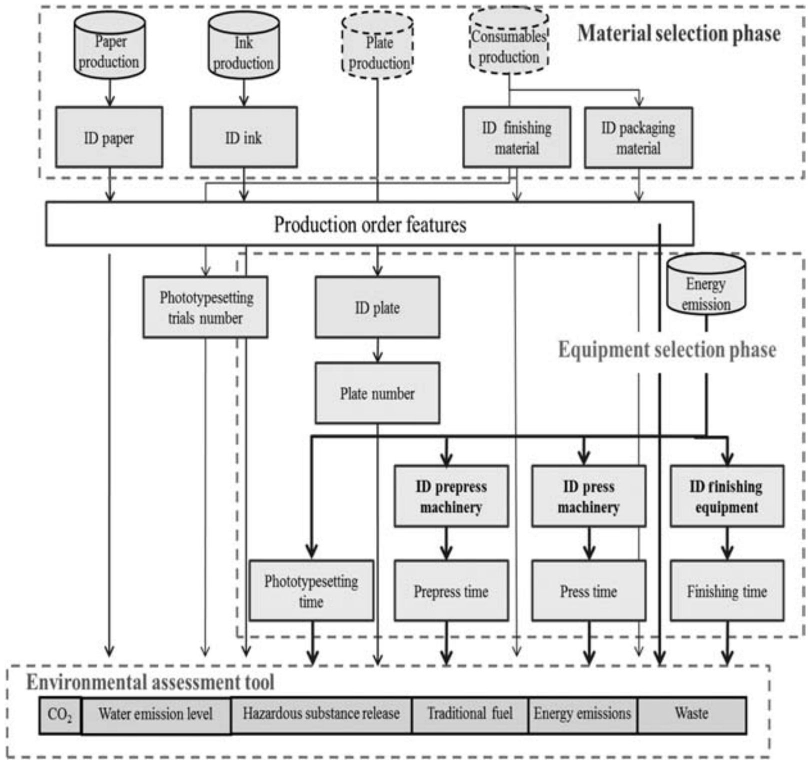

Figure 4. The structure of environmental data analyser.

terms of CO_2 emission could be calculated at the end of the design step when order data were confirmed.

Next, *the equipment selection phase* has to be carried out: four main processes -such as phototypesetting, prepress, printing and finishing processes -were introduced in the proposed prototype. Data on absolute environmental performance of the equipment were deducted by each specific supplier. The *production lead time estimation* phase allows to integrate absolute data on both raw materials and technological process characterisation with information about the specific order: the total number of copies and technological cycle specifications allow to match consumption rates with environmental performance. Each contribution was calculated according to each material and equipment evaluated during product configuration phase; single data were merged in final impact categories in order to point out the whole sustainability level. Proposed impact categories were deducted by ISO 14000 standard; they are detailed as follows:

- *Air emissions*: this category was estimated in terms of kilograms of CO_2 released during all production processes.
- *Water emissions*: they refer to the quantity of water estimated for the specific production order.
- *Hazardous substance releases*: this category refers to the quantity of hazardous substances released.
- *Traditional fuel*: it refers to the quantity of traditional fuels applied in the production process.
- *Energy emissions*: they are usually secondary data on the production of energy.
- *Waste produced*: kilograms of non-hazardous waste produced belong to this category.

3.3 An example case

An applicative example has been proposed in order validate the prototype system; furthermore, a scenario analysis has been proposed. Primary data on the example case are as follows: the printing product analysed is a publicity brochure in A4 format (i.e. 210×297 mm); the total number of copies is 50 and the colour coverage is 90%. Two types of paper were analysed: the first type (defined as *paper 1*) is a recycled paper obtained from non-deinked pulp; the second type (defined as *paper 2*) refers to a recycled paper from the deinked pulp. Deinking is a chemical and physical process usually applied to recycled papers for removing printing ink fillers and other pigments; it increases the brightness of the final product. The process usually involves the use of various chemicals and flotation techniques; thus, it is usually carried out for an aesthetic purpose as environmental impacts due to these treatments could increase. The two types of paper are characterised by the same weight, i.e. 100 g/m^2. Furthermore, two ink types were compared: in the first type, printing is characterised by 47.5% of solvent; in the second type, printing is characterised by 55% of toluene as it guarantees a more glossy effect.

At first, the prototype was acquired from the firm configuration software, input data for the Environmental Data Analyser: the total quantity of paper requested for the production order is 31.2 kg; the total requested ink quantity is 45 kg. Next, the Environmental Data Analyser matches these absolute values with unitary values characterising each material and process equipment from an environmental point of view. It has to be noted that no certified material was purchased by the firm; thus, secondary source of data – about emissions, energy consumption and so on – for the whole life cycle was deducted from a specific database (Ecoinvent 2006). Other raw materials and equipments involved in the production processes are the same in the evaluated scenarios. Thus, results obtained from the Environmental Dashboard are given in Table 2: only the total estimated CO_2 and water emission levels are reported as variations in other impact categories estimated by the prototype were not revealed significantly.

Results show that the product characterised by higher aesthetical features (i.e. Case 22) is characterised by the worst environmental performance in terms of both CO_2 and water emissions. If the same ink type is applied, the use of deinked or non-deinked paper affects most severely estimated water emission levels: the variation between water emission values in Cases 11 and 12 is about 56%; an analogous value (i.e. 52%) was estimated by comparing values of Case 21 versus case 22. Variations in CO_2 emission levels are less sensitive as the estimated variation is about 23% by comparing Case 11 versus case 12, and is about 17% by comparing Case 21 versus case 22.

However, a reduced effect is due to the ink type (i.e. Case 11 vs case 21 and Case 12 vs case 22): the variation is about 33% and 26%, respectively, for estimated CO_2 emission levels. Very slight differences (about 8% and 5%) were estimated for water emissions.

It has to be noted that the estimated results could not be characterised by a general validity, as the aim of the proposed comparison was to outline the potentiality of the proposed prototype system. These results represent a fast but effective assessment of the environmental sustainability level characterising the specific printing product over its entire life cycle; it overcomes limits of traditional eco-labelling schemes as it not only focuses on its raw materials. However, obtained results could not be comparable with traditional LCA analysis which are more detailed and precise: these tools are useless in this case as they require a huge resource effort mainly due to the large number of customisations usually characterising printing products. LCA has revealed to be an effective assessment tool for comparing printing technologies (Veith and Barr 2008) when alternatives are minimal: when the configuration setting is high, the traditional quantitative LCA approach is hard to apply as it is product-centred (Bala *et al.* 2010, Hongli *et al.* 2010). Thus, the proposed decision-support system allows to supply an assessment of environmental performance due to all stages of life cycle characterising a printing product based on simplified impact categories.

Finally, one limit of the current prototype system is due to limited categories of data on raw materials: as an example, five categories of inks were introduced into the current database, but the commercial portfolio is larger.

4. Conclusion

The printing sector is usually affected by a high environmental pressure. Moving towards environmental certification of raw materials, such as pulp and ink, is the current effort of researchers and practitioners. Thus, several effective certification schemes have been proposed all over the world in order to define more sustainable products. However, a unified certification schema of the final product (i.e. a printing product such as a book or a brochure) has not yet been developed. Traditional life cycle analysis (LCA) models could not be so effective as they are based on specific product features; their

Table 2. Estimated values for CO_2 and water emissions in each scenario.

	Contribution due to ink type		Contribution due to paper type			
	Estimated CO_2 level (kg)	Estimated water emission level (m^3)	Estimated CO_2 level (kg)	Estimated water emission level (m^3)	Total CO_2 level (kg)	Total water emission level (m^3)
Ink 1-Paper 1 (case 11)	68.38	191.84	24.11	19.63	92.48	211.47
Ink 1-Paper 2 (case 12)	68.38	191.84	45.29	140.00	113.66	331.83
Ink 2-Paper 1 (case 21)	98.97	209.52	24.11	19.63	123.08	229.15
Ink 2-Paper 2 (case 22)	98.97	209.52	45.29	140.00	144.26	349.52

application requires a very huge effort as the potential number of product customisations is infinitively high.

This study proposes a decision support system aiming to analyse in a fast and effective way, the environmental sustainability level of a printing product. A prototype software tool has been developed in order to support the proposed approach. At the end of the design phase when production order features are definitively fixed, the tool provides a fast assessment of environmental impacts due to the raw material supply and the printing processes carried out by the printing firm. Data on environmental performance of input materials could be derived directly from the supplier (as a primary source of information) if the material is certified, or they are deducted from international databases (as secondary sources of data). Next, results are collected in predefined impact categories, and an environmental dashboard has been developed to supply a fast tool for assessing the environmental sustainability of a printing product during its life cycle. The proposed tool was designed to be integrated with traditional printed product design tools (which carry out cost and time estimation): thus, it could be applied in a planning phase in order to support firms in applying more sustainable strategies. Moreover, as data could be acquired directly during the production phase, actual environmental (and economic) performances could be compared with the estimated performances allowing more effective control activities. Ex-ante environmental analysis results could be compared with production process feedback concerning actual environmental data derived from operational processes. Hence, the obtained information could be applied by the printing firm in order to promote to its customer's a more eco-friendly approach as a sort of environmental product certification, which could be supplied by the proposed model.

Further developments could be oriented to amplify impact categories and sources of unitary data on emissions in order to cover a wider range of products which are currently the main limits of the prototype system.

Acknowledgements

The research programme called INTECOPRINT was co-funded by the Apulian region and by the European Commission F.E.S.R., P.O. Regione Puglia 2007–2013.

References

Ahlroth, S., Nilsson, M., Finnveden, G., Hjelm, O., and Hochschorner, E., 2011. Weighting and valuation in selected environmental systems analysis tools – suggestions for further developments. *Journal of Cleaner Production*, 19, 145–156.

Bala, A., Raugei, M., Benveniste, G., Gazulla, C., and Fullana-i-Palmer, P., 2010. Simplified tools for global warming potential evaluation: when 'good enough' is best. *The International Journal of Life Cycle Assessment*, 15 (5), 489–498.

Bing, Y., Guosheng, C., Lijunc, L., and Peng, Y., 2011. Research and development of carbon footprint analysis in Hunan Province. *Energy Procedia*, 5, 1210–1217.

Bratt, C., Hallstedt, S., Robert, K.H., Broman, G., and Oldmark, J., 2011. Assessment of eco-labeling criteria development from a strategic sustainability perspective. *Journal of Cleaner Production*, 19 (14), 1631–1638.

Canadian Standards Association, 2008. PLUS 14021 – environmental claims: a guide for industry and advertisers [online]. Available at http://shop.csa.ca/en/canada/environmental-labeling/plus-14021-2nd-ed-pub-2008/invt/27010452008/ [Accessed 12 July 2012].

Da Silva, S.P.R., and Amaral, F.G., 2009. An integrated methodology for environmental impacts and costs evaluation in industrial processes. *Journal of Cleaner Production*, 17, 1339–1350.

Ecoinvent, 2006. Documentation of changes implemented in Ecoinvent Data v1.2 and v1.3. Release 2006, Swiss Centre for Life Cycle Inventories, Switzerland.

Environmental Paper Network (EPN), 2011. Paper calculator model – paper calculator version 3.0 [online]. Available from: http://www.papercalculator.org [Accessed 12 July 2012].

Environmental Protection Agency (EPA), 1996. Paper Products Recovered Materials Advisory Notice [online]. Available at: http://www.epa.gov/fedrgstr/EPA-WASTE/1996/May/Day-29/pr-571.txt.html. [Accessed 12 July 2012].

European Union, 2001. Green paper on integrated product policy (IPP) [online]. Available from: http://eur-lex.europa.eu/LexUriServ/site/en/com/2001/com2001_0068en01.pdf. [Accessed 12 July 2012].

European Union, 2009. Regulation No. 66/2010 of the European Parliament and of the Council of 25 November 2009 on the EU Ecolabel [online]. Available from: http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32010R0066:EN:NOT. [Accessed 12 July 2012].

European Union, 2011. Commission Decision of 7 June 2011 on establishing the ecological criteria for the award of the EU Ecolabel for copying and graphic paper [online]. Available from: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32011D0333:EN:NOT. [Accessed 12 July 2012].

Finnveden, G., and Mobergc, A., 2005. Environmental systems analysis tools e an overview. *Journal of Cleaner Production*, 13, 1165–1173.

Flores, M., Canetta, L., Castrovinci, A., Pedrazzoli, P., Longhi, R., and Boër, C.R., 2008. Towards an integrated framework for sustainable innovation. *International Journal of Sustainable Engineering*, 1 (4), 278–286.

Ghorbannezhad, P., Azizi, M., Ting, S., Layeghi, M., and Ramezani, O., 2011. Cleaner production: a case study of Kaveh paper mill. *International Journal of Sustainable Engineering*, 4 (1), 68–74.

Halog, A., 2004. An approach to selection of sustainable product improvement alternatives with data uncertainty. *The Journal of Sustainable Product Design*, 4 (1–4), 3–19.

Hermann, B.G., Kroeze, C., and Jawjit, W., 2007. Assessing environmental performance by combining life cycle assessment, multi-criteria analysis and environmental performance indicators. *Journal of Cleaner Production*, 15, 1787–1796.

Herrup, A., 1999. Eco-labels: benefits uncertain, impacts unclear? *European Energy and Environmental Law Review*, 8, 144–153.

Hewlett-Packard, 2009. HP carbon footprint calculator for home and business computing products [online]. Available from: http://www.hp.com/large/ipg/ecological-printing-solutions/carbon-footprint-calc.html [Accessed 12 July 2012].

Hongli, F., Rubin, O.D., and Babcock, B.A., 2010. Greenhouse gas impacts of ethanol from Iowa corn: life cycle assessment versus system wide approach. *Biomass and Bioenergy*, 34 (6), 912–921.

ISO, 1994. ISO 9706:1994. Information and documentation. Paper for documents – requirements for permanence.

ISO, 2000. ISO 14020:2000. Environmental labels and declarations. General principles.

ISO, 2007. ISO 14001:2004. Environmental management systems – Requirements with guidance for use.

Laurent, A., Olsen, S.I., and Hauschild, M.Z., 2010. Carbon footprint as environmental performance indicator for the manufacturing industry. *CIRP Annals – Manufacturing Technology*, 59, 37–40.

Montero, E., Hawker, J.S., Esterman, M., and Rothenberg, S., 2010. *Sustainable printing activities: design and initial approach of a print energy life-cycle decision tool – a research monograph of the printing industry Center at RIT Rochester*. NY, USA: RIT Printing Center, No. PICRM-2010-03.

National Association of Paper Merchants (NAPM), 2011. Recycled mark. [online]. Available from: http://www.napm.org.uk/recycled_mark.htm [Accessed 12 July 2012].

Nike, 2010. Nike environmental design tool [online]. Available from: http://www.nikebiz.com/Default.aspx [Accessed 12 July 2012].

Nordic Ecolabeling, 2003. Swan labeling of paper products – basic module [online]. Available from: http://www.nordic-ecolabel.org/criteria/product-groups/. [Accessed 12 July 2012].

Pandey, D., Agrawal, M., and Pandey, J.M., 2011. Carbon footprint: current methods of estimation. *Environmental Monitoring and Assessment*, 178, 135–160.

RAL gGmbH, 2009. Der Blaue Engel, basic criteria for award of the environmental label – recycled paper – RAL-UZ 14.

Singapore Environment Council, 2011. Singapore Green Labeling Scheme. Standards and criteria [online]. Available from: http://www.greenlabel.sg/sgls [Accessed 12 July 2012].

Solomon, K., Bergman, H., Huggett, R., Mackay, D., and McKague, B., 1993. A review and assessment of the ecological risks associated with the use of chlorine dioxide for the bleaching of pulp. Report for the Alliance for Environmental Technology [online]. Available at : http://infohouse.p2ric.org/ref/14/13028/solomon_2.pdf [Accessed 12 July 2012].

Sundarakani, B., De Souza, R., Goh, M., Wagner, S.M., and Manikandan, S., 2010. Modeling carbon footprints across the supply chain. *International Journal of Production Economics*, 128 (2010), 43–50.

Veith, S., and Barr, S., 2008. Life cycle assessment: flexographic and rotogravure printing comparison & flexographic plate imaging technologies. Dupont Engineering and Research Technology [online]. Available from: http://www2.dupont.com/Packaging_Graphics/en_US/assets/downloads/pdf/FlexoGravure_LCA_PublicReport.pdf. [Accessed 12 July 2012].

Wong, Y.L., Leeb, K.M., and Yung, K.C., 2010. Model scenario for integrated environmental product assessment at the use of raw materials stage of a product. *Resources, Conservation and Recycling*, 54, 841–850.

Xerox, 2008. The Xerox sustainability calculator [online]. Available from: http://www.consulting.xerox.com/flash/thoughtleaders/suscalc/xeroxCalc.html. [Accessed 12 July 2012].