Sustainable car lifecycle design

taking inspiration from natural systems and thermodynamics

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Abstract—**This paper exposes the search for a tool and method, which from a systems approach, adopts the rules and logic that govern our physical context (biosphere) in order to provide guidelines that the car industry could use to achieve an ideal state for ecological, economical and social sustainability.** *(Abstract)*

Keywords-component; car; natural systems; sustainability; industry

I. INTRODUCTION

In the last decade the world economy has been struggling with severe endemic problems [1,2,3] and design is integral to them [4]. Designing, producing and consuming under the cradle-to-grave philosophy will lead to a severe scarcity of resources among many other significant problems [5,6,7,8,9]. In the design profession is important to search beyond our field to find broader possibilities in order to increase the designer's potential for sustainable product development and expanding design activities and influence.

This paper exposes the search for a tool and method, which from a systems approach, adopts the rules and logic that govern our physical context (biosphere) in order to provide guidelines that the car industry could use to achieve an ideal state for ecological, economical and social sustainability. Therefore, understanding the boundaries of Earth's resources, the economic structure that organises it all and what equitable human well being levels should be pursued is mandatory. A new car industry should respond in novel ways to variables like the ecosystem carrying capacity, energy flows and matter transfer, population number, its distribution and growing rate, allocation of benefits, business and service models and ultimately aspire to an absolute decoupling [6] of physical objects production from the pursuing of human well being.

According to the International Road Federation there are nowadays more than 600 million cars running in the world's streets [10]. All together they are responsible for 6.3% of global CO2 emissions [11]. In the US alone, paradigm of western civilisation, it is estimated that 60% of all national carbon dioxide emissions are emitted by motor vehicles [12]. Beyond the amount of vehicles, we must also consider the powerful fact that cars have become a psychological need, a cultural reference and even part of the structure of human society. "It is very unlikely that everyone in the future will be travelling on foot and by bike, and specially not by public bus… and the individual flexibility, comfort and convenience the car provides is going to disappear" [13].

Since its first appearance in the beginning of 20th century cars have been associated with freedom and very soon were displayed as an emblem of social status. The amazing energy embedded in fossil fuels and its rapidly falling cost, together with Ford's production lines provided cars to millions of people in just a few years; the car industry became the pinnacle of the industrial revolution and modern society. Timothy O'Brien, Deputy Chief of Staff Ford Motor Company, declares that 50,000 pounds of raw materials are necessary to create a vehicle of 3,000 pounds, showing an efficiency of just 6% [14].

Together with the industrial revolution the primary base on which our economy and society performs was developed: the consumption of goods; however, once the basic needs were covered, other tools were necessary to keep on consuming products that sustained economic growth and thus welfare. It was then, when planned and perceived obsolescence came into play, that Schumpeter called it "creative destruction". Nowadays the social trend of consuming products as fast as possible is to maintain the primary structure of economic growth and ideally through it welfare [6].

II. IMPLICATIONS

The creation of mass produced goods is evidently related to the use of materials derived from natural resources that, currently, can only be found on our planet; and in the energy required to transform that matter, mainly obtained from fossil fuels. The very structure in which our economy functions is taking Earth's resources to its limits [5], due to the neoclassical economist important miscalculation of considering the planet's biosphere and its resources, as part of the economic system, which must grow continuously in order to provide welfare, thus perceiving them as limitless [15]. Many implications can be subtracted from this situation; the more evident ones are the depletion of ecosystems and non-renewable resources, whereas other ones being less evident as missing the ultimate goal of economic growth: bringing well being to the entire population. The strongest evidence in this sense is that basic elements of human well being like life expectancy and accessibility to education have no correlation with increasing per capita GDP beyond a certain point [16,17,18].

The basic index most nations use for measuring growth is Gross Domestic Product (GDP); which basically is "the sum of all value added to raw materials by labour and capital at each stage of production, during a given year" [15]. With this definition we can infer that the more efficient the labour is, the less capital is needed and more added value can be obtained. This basic fact is what makes technological improvements happen, the continuous search of efficiency; which in turn creates another complex linkage with the urgent need for continuous growth: the balance of unemployment [6]. In order to keep people employed and avoid social collapse more products must be created. This trend is well defined by Jevons' paradox [19]. The way we design, build and use products, and even keep social cohesion is based on a constant structural need for avoiding collapse, fed by positive feedback loops that only increase its negative impacts.

With this basic concept in mind it is clear that searching for a possible solution to our physical limits, and ensuring a future without resource scarcity implies changes in economic, social and environmental systems. Under the same logic the evident response to the dilemma of growth is the concept of decoupling, by "reducing the rate of use of resources per unit of economic activity" [20,21](OCDE, 2002; and UNEP, 2011). This is a controversial issue, when countries like Germany or the UK today claim consumption reduction and GDP growth, therefore evidence of decoupling, what is really happening is the externalisation of costs, as many impacts are being exported to developing countries like China. Looking at global statistics of CO2 emissions, loss of ecosystems and social inequality they are still growing [6], giving an even greater systemic attribute to the challenge.

Within this context and the inevitable need for urban mobility the next questions arise:

- How should the car industry and its products react to address these systemic issues?

- What manufacturing and distribution processes, materials and business models can change the current pattern and play under biosphere and resources rules?

- What behaviour must we encourage in users (e.g. culture), manufacturers (e.g. production systems) and governments (e.g. policies)?

- What products will look like? How, where and who is going to produce them and under which business models will they reach users in a decoupled economy?

These questions are formulated from an industrial design point of view; if we are to manufacture products in order to satisfy user needs it is imperative to change today's perspective and tackle the challenge in a 'systems approach'. To do so it is necessary to adopt a multidisciplinary understanding of each professional area in order to discover what knowledge has been created and what tools can Industrial Design find useful. Therefore, literature review was performed on the topics relevant to this research and the next findings are proposed as starting ground knowledge for the development of such tool.

III. MEASURING IMPACT

The most commonly used tool to measure impact is Life Cycle Assessment (LCA). It is a highly complex, long and expensive process, which ultimately will not result in a "sustainable grade" as it will only identify areas where work is needed. Its accuracy and the criteria used to create final reports can be used to "mask" bad products [22].

Other similar tools where identified: Product Lifecycle Management [23] and Eco-costs [24] among the most popular ones. Both tools, with different approaches, deal with the same parameters, measuring impacts on human manufacturing and distribution.

The Wuppertal Institute for Climate, Environment and Energy has developed the Material Input Per Service unit (MIPS), which is an indicator of material usage in the manufacture of a product or service; it intends to stimulate business decisions towards efficient resources use and management. MIPS calculate the resource extraction from the source and the related impacts against the amount of service it performs [25].

IV. ECOSYSTEM STRUCTURE

Life is organised in the most efficient way as consequence of 3.7 billion years of evolution. All matter and energy flows within the Earth's system under very specific physics and chemistry laws. When it comes to life, organisms are classified according to their role in the food chain, in it Trophic Levels is where energy flows and matter transfer occurs [26].

In the first level can be found the Autotrophs; more simply called Photosinthesizers. The next level features Heterotrophs, within these there are Herbivores, Carnivores and Omnivores. Finally the Detritivores, which are important organisms in charge of decomposing organic matter again into basic chemical compounds. Each level aims to obtain enough energy to perform work in the form of: growth and reproduction. The interactions among trophic levels plus the environment that sustains them is called an ecosystem [26].

Müller [27] discussed the potentials of self-organisation, based on the ecological principle called orientors, a system-based theory on ecosystem development founded in non-equilibrium thermodynamics and network development. The selection of orientors is strictly related to the understanding of the "Eco-targets" within the analysed ecosystem, these differ among ecosystems in relation to contextual conditions. "So far as ecological systems are characterised by a very high capability for self-organisation and have been evolving for billions of years it makes sense to use and apply the orientors' signals in practical management of a more near-nature manner, that can prove to be a profound and promising strategy which contributes to the ecological goals of sustainable development" [28]. Bossel [29] proposes 7 basic orientors that can be applied to any ecosystem: Existence, Effectiveness, Freedom of action, Security, Adaptability, Coexistence and Psychological needs.

V. THERMODYNAMICS AND EMERGY

The first physical laws to consider when examining Trophic Structures derive from thermodynamics. In each level only a small amount of energy is passed to the next level (exergy), this is due to the loss of energy (entropy) and by cellular respiration and energy transferred to detritivores [26]. This fundamental fact explains why each consequent level is smaller than the previous one and population's distribution patterns and reproduction rates [26].

According to Odum [30] emergy (written with an m) is the amount of energy that is used up in transformations directly and indirectly to make a product or service. The name is derived from "embedded energy". Almeida [31] proposes it as an "environmental accounting method… as a tool to assist in product design". Odum [32] clarifies the terms: energy hierarchy, energy scale and transformity, besides illustrating the profound meaning of the emergy accounting and its impact on our ecosystems.

VI. ECOSYSTEM CARRYING CAPACITY

Each ecosystem, according to the nutrients it contains, has a specific carrying capacity; this defines the maximum number of individuals the environment can support [26], and help us understand the energy flows, efficiency, population number, growing rate and distribution patterns.

In 1990 researchers Mathis Wackernagel and William Rees at the University of British Columbia created the concept of Ecological Footprint that measures the land and water area a human population requires to produce the resources it consumes and to absorb waste. [33,34]. They developed an efficient way of measuring ecosystem carrying capacities: land and water area are scaled according to its biological productivity. This scaling makes it possible to compare ecosystems with different bio-productivity in different areas of the world [33]. It follows that:

Bio-Capacity = Area x Yield factor x Equivalence factor

The yield factor is the ratio of national-to world-average throughput. The equivalence factor translates the area supplied or demanded of a specific land use type into units of world average biologically productivity, which varies by land use type and year [33].

The Millennium Ecosystem Assessment promoted by the UN "assess the consequences of ecosystem change for human Wellbeing and the scientific basis for action needed to enhance the conservation and sustainable use of those systems and their contribution to human Wellbeing" [35].

VII. HUMAN WELLBEING

The ultimate purpose of economy, production and progress should be to provide well being to humans. GDP creator Simon Kuznets stated in the US congress in 1934 "the welfare of a nation can scarcely be inferred from a measure of national income" [36]. It is still today a matter of high controversy to define what wellbeing is, but it is clear that economy should ensure it; and a way of keeping track of it must be put into practice, as well as take it into consideration as companies' social responsibility.

The Well being Institute of Cambridge University refers to it as "positive and sustainable characteristics which enable individuals and organisations to thrive and flourish". Manzini proposes a change of society's search for fulfilment from a "product based" to a "context based" [7]. Jackson writes about shifting our "novelty driven" society into a "flourishing" one [6].

The Human Development Index, created by the UN's Development Program is a summary of human development in 3 dimensions: Long and healthy life, Access to knowledge and Decent standard of living [17].

VIII. ECONOMICS AND BUSINESS

It has been mentioned above the unavoidable relation between ecological, social and economical sustainability. The same applies to the severe omissions of neoclassical economics. However, there is relevant research on finding new structures in economy, which are more coherent with today's global context and the physical and chemical laws that govern it. For this research Ecological Economics is highly relevant; it is founded in the works of Georgescu-Roegen, Boulding, Daly and Constanza who proposed a "qualitative improvement in the ability to satisfy wants (human needs and desires) without quantitative increase in throughput beyond environmental carrying capacity" [15]. This is achieved "through thermodynamics and entropy throughput and flows" [15].

“The common denominator of all usefulness, consist of low-entropy matter-energy. Technological knowledge help us use low entropy more efficiently; it does not enable us to eliminate or reverse the direction of metabolic flow” [15].

In a conference held at the University of Vermont in 2003 [37], Daly described the focus of ecological economics through: Allocation of resources, Distribution of income and Scale of the economy relative to the ecosystem upon which is reliant.

Daly’s view on scale is particularly important due to the exponential growth of population and uneven distribution and the difference of ecological services among ecosystems. He states that limiting scale will increase efficiency; and he proposes an ecosystem valuation with two different types of values [37]: Direct use and Indirect use value.

Georgescu-Roegen proposes the differentiation from flow and service as follows: Amount of flow is equal to the units of substance; the rate of flow is equal to the substance consumed in a period of time and service is equal to the substance multiplied by the time it keeps on delivering its function. This is fundamentally due to the fact that “only flows can be embodied in a product… services on the other hand belong to mixed dimensionality in which time enters as a factor”. Hence there is a clear “connection between low entropy and economic value” [38].

In general, ecological economists believe that infinite growth (also referred as “business as usual”) can turn out to be uneconomic, as true costs of growth are higher than the benefits. As a result the optimum scale of economies is often questioned.

The way economic structures operate on a daily basis and deliver value to people is through businesses that directly operate, transform and deliver matter in the form of goods. All businesses run under a model on which the main characteristics and performance of a company are regulated. Osterwalder & Pigneur produced the most relevant work found on business model innovation, they propose a canvas on which 9 consecutive phases must be followed in order to innovate in business model generation [39].

IX. Reflecting upon Literature Findings

What has been previously discussed is the absolute lack of consideration for the limits of our biosphere in neoclassical economics structure, terms that in turn defines the way we manufacture, distribute, use and dispose of products. With this in mind it is clear that it is imperative to work within the boundaries and under the same rules that dominate the natural world. Therefore, it was decided to take a top-down approach. This means setting first the desirable performing outputs of a new car industry with the lowest possible impact. Then the aim is to go backwards to define the new structure characteristics (product, service, business model).

A first clear conclusion is that there is useful ground knowledge in areas like biology, ecology, economics, business and social sciences in order to answer, from an industrial design point of view, the key questions formulated above.

At this stage of the research process the most relevant finding is the concept of trophic level organisation, which in itself contains energy, biomass exchange and its flow, as well as derived important issues of population size and distribution, all ruled by thermodynamic laws. An analogy of these levels in natural systems needs to be drawn alongside the initial idea of economic and matter flow in a production/distribution human system.

It is relevant to note the opportunity to work with production and business structures, its distributions and allocations, since this could lead to “production capacity” and in turn to a distributed business and manufactured.

It is the main task of this research project to build upon that knowledge, and through the understanding and use of ecosystems carrying capacities, thermodynamics and emergy accounting create a tool that leads to an advanced and sustainable way of designing, producing, distributing and using vehicles.

The way this tool is intended to work is first by defining the product to be developed, population segment addressed and the geographical areas from which the resources will be taken from as well as the amount required and industrial processes that will transform them into the final product. According to these variables the boundaries and characteristics for the new structure will be identified.

X. Aims and Objectives

Considering the fixed amount of resources as “generic variables”, the increasing amount of population and its urbanisation distribution patterns trends a first hypothesis is proposed:

By analysing sustainable performance from a natural systems point of view through the trophic structure of energy flow and biomass transfer (thermodynamics), the boundaries and mechanics of a sustainable car industry can be identified for later structuring it by using a business model innovation tool. This may generate as output new business models and manufacturing/product characteristics for each geographical region, these while remaining feasible with the decoupling of progress and prosperity from resources depletion.

In order to achieve this a method to develop a new structure from the “generic variables” will be created. Starting from the ground knowledge the different variables such as: ecosystems location and area, human population distribution, human population growth rate, renewable resources characteristics, sustainable rate of consumption, ecosystem waste absorption rate, etc. will be input and acoherent distributed business/production/service model will be deployed for each case.

XI. Expected contribution

From a theoretical point of view the use of trophic structures and the combination of knowledge from biology, economics, thermodynamics and business that reside in the proposed method will increase the designer's potential for sustainable product development deriving in a novelty approach for design activities and influence. The direct research contribution is intended to be a tool that will guideline the way for sustainable innovation in the automotive industry where vehicles can be designed, produced, distributed and put into use with the lowest possible ecological impact and socially responsible, as well as an integral evaluation method incorporating ecological, economical and social measurements.

XII. Methodology

The methodology adopted to achieve this research expected contributions is divided in two main phases. The first one relates to the build up of the structure and contents of the proposed method, which requires deep knowledge of the multiple perspectives involved in generating the criterion to select the generic variables to use and understand their interconnections, all of these will be translated in a set of relevant and manageable data. English [40] proposes a multiple perspective problem framing method, which through the use of integrated mind mapping, design space framing and the development of different mental models the network and its interrelations, can be analysed and the designer's perception developed.

Once the variables are identified, the necessary data collection will be mainly performed through accessing global statistics from institutions like United Nations Development Program, United Nations Environment Program, World Bank, International Monetary Found, etc. For each data category it will be indispensable to set the boundaries of sustainable performance (that often depends on other variables due to complex network interconnections), which would be stated by the Ecological footprint method and the Millennium Ecosystem Index. It is foreseen that for this step mapping the system will be necessary in order to understand the interconnections among variables and be able to build the economy, matter and energy relations that are impossible to predict. Research has been conducted and several free open-source complex network mapping software have been found, the most relevant ones are: Pajek, Graph-tool, Tulip, NteworkX and Processing, which is particularly important for its design capabilities.

The last part of phase one will be to analyse the business model innovation steps in order to reorganise them more coherently with the trophic structures (resource-driven) for later function as filters and give shape to the new proposals into practical applications. These business model steps have been mentioned above, some of them are: value proposition, production processes, production quantities, facilities distribution, key infrastructure, etc.

The second phase will be about testing the tool by designing an experiment within which different design groups can use the proposed tool in order to create products solutions for geographical areas determined in cases designed specifically for this experiment. It is planned to have three different cases and rotate them among three design groups, in order to have proposals for the same problem coming from different participants. The outcomes then will be measured and compared in relation to their ecological and social impact using the Ecological footprint tool, the Millennium Ecosystem Index and the Human Development Index. Comparing the results will enable the process of drawing conclusions about the effectiveness of the tool.

Due to the complexity of data management and interaction, the tool is planned to be a computer application on which variables can be introduced so that the user can modify parameters and in real time see graphically the results of its choices in order to determine the best option. A collaboration agreement has been achieved between the School of Design and the Computer, Engineering and Information Sciences faculty, both from Northumbria University, to develop the software by master computing students under the requirements of this research.

XIII. Conclusion

Even though the relation of climate change and its human origin is still a matter of debate in some forums, and the reluctance of neoclassic economics in facing the limiting characteristics of our natural context, there is no argument against the search of resource efficiency and a possible economic benefit from it. This paper discussed a possible way of organising new knowledge (new for the industrial design profession) in order to find more efficient ways of manufacturing, using and disposing of our products.

The research objectives are aligned with the UK government agenda to reduce CO2 emissions by 50% by the year 2050 and to develop at the same time a low carbon economy.

References

[1] Krugman, P. (2008) Running out of planet to exploit, The New York Times. [On line]. Available at:

http://www.nytimes.com/2008/04/21/opinion/21krugman.html?ref=paulkrugman

[2] Stiglitz, J. (2010) Why we have to change capitalism, The Telegraph. [On line]. Available at: http://www.telegraph.co.uk/finance/newsbysector/banksandfinance/7061058/Joseph-Stiglitz-Why-we-have-to-change-capitalism.html

[3] Brooks, D. (2011) The lost decade? The New York Times. [On line]. Available at: http://www.nytimes.com/2011/09/27/opinion/brooks-the-lost-decade.html?_r=3&ref=columnists

[4] Manzini, E. (2009) 'New design knowledge', *Design studies*, Volume 30, Issue 1, January 2009, pp. 4-12

[5] Heinberg, R. (2007) *Peak everything: waking up to the century of decline in Earth's resources*, Clairview Books, London, UK.

[6] Jackson, T. (2009) *Prosperity without growth, economics for a finite planet*. Ed Earthscan, 3th ed 2011, London, UK.

[7] Manzini, E. (2007) 'Design, social innovation and sustainable ways of living', DIS-Indaco, Politecnico di Milano [On line]. Available at: http://www.ngd.ufsc.br/arquivos/giselle/Ezio-Manzini-DESIGN.ISDS-v.2.pdf (Accessed October 2011)

[8] McDonough, W. Braungart M. (2002) *Cradle to Cradle*. Rodale Press, New York, USA.

[9] Meadows, D. Randers, J. Meadows, D. (2004) *Limits to growth: the 30-year update*, Earthscan, London.

[10] International Road Federation (2002) Worldmapper, Available at: http://www.worldmapper.org/display.php?selected=31# (Accessed: October 2011)

[11] Stern, N. (2007) *The Stern Review, The Economics of Climate Change*. Cambridge University Press.

[12] Black, E. (2006) *Internal Combustion: How Corporations and Governments Addicted the World to Oil and Derailed the Alternatives*. New York: St Martin's Press (p. 262)

[13] Kingsley, D. Urry, J. (2009) *After the car*. Ed Polity Press, 2nd ed. Cambridge, UK

[14] *Waste = food* (2006) Directed by Rob van Hattum [Film]. Brooklyn, NY: Icarus Films

[15] Daly, H., Farley, J (2004) *Ecological economics, principles and applications*. Island press, Washington DC.

[16] HDR UNDP (2011) *Human Development Report, Sustainability and equity: a better future for all* [On line]. Available at: http://hdr.undp.org/en/reports/global/hdr2011/download/ (Accessed: October 2011)

[17] UNDP (2011) *Human Development Index Report* [On line]. Available at: http://hdr.undp.org/en/media/HDR_2011_EN_Complete.pdf (Accessed: September 2011)

[18] Rosling, H. (2006) *Hans Rosling shows the best stats you've ever seen, TED talk* [Download]. Available at: http://www.ted.com/talks/hans_rosling_shows_the_best_stats_you_ve_ever_seen.html (Accessed: September 2011)

[19] Jevons, S. (1865) The Coal Question; An Inquiry Concerning the Progress of the Nation and the Probable Exhaustion of Our Coal-Mines. an Inquiry Concerning the Progress. Ed Macmillan and Co, 1st ed 1865, London UK. [On line]. Available at: http://books.google.co.uk/books?id=gAAKAAAAIAAJ&printsec=frontcover&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false

[20] OCDE (2002) *Indicators to measure decoupling of environmental pressure from economic growth. Executive summary*. Available at: http://www.oecd.org/dataoecd/0/52/1933638.pdf (Accessed: September 2011)

[21] UNEP (2011) *Decoupling natural resource use and environmental impacts from economic growth, A Report of the Working Group on Decoupling to the International Resource Panel*. Fischer-Kowalski, M., Swilling, M., von Weizsäcker, E.U., Ren, Y., Moriguchi, Y., Crane, W., Krausmann, F., Eisenmenger, N., Giljum, S., Hennicke, P., Romero Lankao, P., Siriban Manalang, A. [On line]. Available at: http://www.unep.org/resourcepanel/decoupling/files/pdf/decoupling_report_english.pdf (Accessed: September 2011)

[22] Environmental Protection Agency (2006) *Life Cycle Assessment: principles and practice* [On line]. Available at: http://www.epa.gov/nrmrl/lcaccess/lca101.html (Accessed: October 2011)

[23] PLM TG (2011) *Product Lifecycle Management Technology Guide* [On line]. Available at: http://plmtechnologyguide.com (Accessed: October 2011)

[24] TU Delft (2011) *Eco-cost* [On line]. Available at: http://www.ecocostsvalue.com/ (Accessed September 2011)

[25] Ritthoff, M. et al. (2002) 'Calculating MIPS, Resource productivity of products and services'. Wuppertal Institute for Climate, Environment and Energy. [On line]. Available at: http://www.wupperinst.org/en/projects/topics_online/mips/index.html

[26] Mader, S. (2010) *Biology*, McGraw-Hill Education, 10th ed. London, UK.

[27] Müeller, F. (2005) 'Indicating ecosystem and landscape organization', Ecological Indicators 5 (2005) 280–294

[28] Scott, F. Witte, K. (2009) 'Ecosystem Theories - Orientor Theory', University of Kiel, Ecology Centre. In: Müller F. and Leupelt M. (1998): 'Eco targets, goal functions, and orientors'. Berlin. Heidelberg. pp 13-18.

[29] Bossel, H. 2001. 'Assessing viability and sustainability: a systems-based approach for deriving comprehensive indicator sets'. Conservation Ecology **5**(2): 12. [On line]. Available at: http://www.consecol.org/vol5/iss2/art12/

[30] Odum, H.T. (1996) *Environmental Accounting: Emergy and Environmental Policy Making*. John Wiley and Sons, New York. p370

[31] Almeida, C.M.V.B., Rodrigues, A.J.M., Bonilla, S.H., Giannetti, B.F. (2010) 'Emergy as a tool for Ecodesign: evaluating materials selection for beverage packages in Brazil'. Journal of Cleaner Production 18, pp. 32–43

[32] Odum, H. T. (1998) 'Emergy evaluation', *International Workshop on Advances in Energy Studies: Energy flows in ecology and economy*, Porto Venere, Italy, May 27,1998

[33] Ewing, B., Reed, A., Galli, A., Kitzes, J., and Wackernagel, M. (2010a) *Calculation Methodology for the National Footprint Accounts, 2010 Edition.* [On line]. Available at: http://www.footprintnetwork.org/images/uploads/National_Footprint_Accounts_Method_Paper_2010.pdf (Accessed: October 2011)

[34] Ewing, B., Moore, D., Goldfinger, S., Oursler, A., Reed, A., and Wackernagel, M. (2010b) *The Ecological Footprint Atlas 2010.* [On line]. Available at: http://www.footprintnetwork.org/en/index.php/GFN/page/ecological_footprint_atlas_2010 (Accessed: October 2011)

[35] Millenium Ecosystem Assessment (2011) *Ecosystems and human well-being, opportunities and challenges for businesses and industry* [On line]. Available at: http://www.maweb.org/documents/document.353.aspx.pdf (Accessed: October 2011)

[36] Kuznets, S. (1934) National income, 1929-1932, US Senate 73d congress report, 2d session, Washington, D.C., U.S. Government printing office, 1934

[37] GundInstitute (2011) *Dr. Herman Daly: Sustainability and the scale of the economy*. Available at: http://www.youtube.com/watch?v=rgeV3dpaRJ0 (Accessed: October 2011)

[38] Georgescu-Roegen, N. (1999) *The entropy law and the economic process*, Harvard University Press/toExcel, Cambridge, Mass.

[39] Osterwalder, A., Pigneur, Y. (2010) *Business model generation: a handbook for visionaries, game changers, and challengers*. John Wiley & sons, Hoboken, N.J.

[40] English, S. (2011) *Multiple Perspective Problem Framing, How do designers think about situations to reveal hidden opportunities?* PhD published, Northumbria University, UK.