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State-of-the-Art in E-Commerce Carbon Footprinting

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Abstract

This paper provides a survey of the state-of-the-art in E-Commerce Carbon Footprinting. This comprehensive literature survey informs the research community on past and recent objective and subjective efforts towards measuring Eco-Efficiency and Eco-Efficacy of E-Commerce. Moreover, this paper provides a framework for categorizing research in this critical area. We also provide a summary of some very promising future research directions in Carbon Footprinting of E-Commerce. Our survey corroborates that Carbon Footprinting is now considered a widely recognized broad framework of gauging Eco-Efficiency and Eco-Efficacy of E-Commerce. Furthermore, it informs us that the research in this discipline is fast expanding and evolving. Such a survey in this critical research field is significant for government and corporate policy-makers in formulating informed decisions regarding Sustainability. In addition, the research in this domain may be useful to environmentally conscious consumers who want to make informed choices on their consumption habits for reducing their personal Carbon Footprints.

Keywords: **E-Commerce, Supply Chain Management, Carbon Footprinting, Sustainability, Eco-Efficiency, Eco-Efficacy.**

INTRODUCTION

The growing evidence that modern human activities are quickly deteriorating the environmental sustainability of our planet has made the notion of Sustainability a major focus of humankind. Nevertheless, the whole humanity needs to join the common efforts

in minimizing the greenhouse effects by living “green” and reaching a sustainable existence by creating efficient business models and practices. However, in order to assess the impact of various factors and complex underlying dynamics, we often need some quantitative and qualitative frameworks and models to make objective decisions (Ahmad, 1997; Ben-Daya and Rahim, 2003).

In general, there have been some research efforts where such models and frameworks for assessing Sustainability have been proposed. For instance, there is the standard model of Sustainability Assessment, often referred to as the Triple Bottom Line (TBL) in the industry, that expands the focus of governments and businesses from purely financial performance to an integration of social, ecological, and financial performances (Klöpffer, 2008). This Sustainability assessment model is a whole life cycle analysis from cradle to grave for products, systems, services, and processes. It is directed at assessing the Sustainability triad constituting of the social, ecological, and financial aspects. The first aspect is ascertained by the Social Life Cycle Assessment or SLCA, the second aspect by the Life Cycle Costing or LCC, and the last aspect by the Life Cycle Assessment or LCA (Ibid).

Interestingly, the advent of the Information Age has facilitated the development and procurement of exclusively new business models, value propositions, and more efficient organizations (Castells, 2000a, 2000b, 2001, 2004). Indeed, the Internet plays a major part in such a digital integration, providing the infrastructure of choice for E-Commerce. In fact, the Internet offers governments and businesses easier and efficient means to link with customers and other enterprises. Moreover, the Internet offers the promise for reducing the transaction costs for organizations (Laudon and Laudon, 2007; Brynjolfsson and Smith, 2000). Consequently, E-Commerce holds significant potential in reducing carbon emissions due to its cost-effectiveness to businesses and governments.

In fact, E-Commerce has frequently been proposed as a way of improving Sustainability through the potential reduction in carbon emissions. Nevertheless, despite all promises offered by E-Commerce towards reducing harmful emissions, there are important factors that must be considered prior to making a final decision on whether or not the Carbon Footprint created by E-Commerce is smaller than that of the traditional commerce. In past, some research has been done towards gauging the Carbon Footprint of various E-Commerce activities. This paper is intended to provide an extensive and integrative survey of the past research efforts in E-Commerce Carbon Footprinting. We believe that such a literature survey would facilitate future research by providing a good reference on this issue.

The rest of the paper is organized as follows: Section 1 provides some historical perspective on Carbon Footprinting, Section 2 presents a case for research in E-Commerce Carbon Footprinting, Section 3 provides an extensive literature survey in this domain, Section 4 tenders some interesting and challenging future research directions, and Section 5 concludes the paper with a summary.

HISTORICAL PERSPECTIVE

Currently, our planet Earth is experiencing its highest average surface temperature for the last 100,000 years. Among other factors, our climate is profoundly affected by

emissions of GHGs. Indeed, the amounts of the GHGs in our atmosphere are above the normal, resulting in a warmer planet (McMichael and Woodruff, 2004). As one study informs us that "the Earth's has warmed by at least 0.2°C every year during the past 20 years or so – about the same amount by which it has warmed or cooled over the space of a century in the past" (Mann and Jones, 2003). This argumentation of the GHGs started after the first industrial revolution around 1750 and emanated mainly from burning of fossil fuels and clearing of forests (McMichael and Woodruff, 2004).

Before the industrial revolution, the air held no more than 275 ppm CO_2 and now it has 385 ppm CO_2 (Hansen et al., 2008). Essentially, the experts stated, "If humanity wishes to preserve a planet similar to that on which civilization developed and to which life on Earth is adapted…CO_2 will need to be reduced from its current 385 ppm to at most 350 ppm" (Ibid.). As such, the reduction in GHGs has become an important goal at the global level.

Nevertheless, a new world is taking shape in this beginning of the third millennium. Three major independent processes fundamentally alter our world: the information technology and systems revolution, the financial crisis, and environment-centered social movements. The contemporary society reflects on the consequences of these processes, which are affecting the very existence of humanity in the global village (Castells, 2000a, 2000b, 2001, 2004). Such reflections and considerations are made at international, regional, organizational, and individual levels. Currently several companies in the World exploit technology and thus advocate Green IT by implementing innovation, for instance Accenture, Boston Consulting Group, Capgimini, General Electric, HP, IBM, Infosys, McKinsey, TCS and PWC (Accenture, 2009; Boston Consulting Group, 2009; Capgimini, 2009; General Electric, 2009; HP, 2009; IBM, 2009; Infosys, 2009; McKinsey, 2009; TCS, 2009; PWC, 2009).

For instance, in 1987, the Montreal Protocol focused on reducing ozone depletion caused by anthropogenic emissions like chlorofluorocarbons with some success (UNEP, 2002). However, the importance of carbon dioxide as a major contributor to anthropogenic greenhouse gases (GHG) cannot be overestimated. In 1997, the United Nations stated the Kyoto Protocol to control the emission of carbon dioxide and the other GHGs of industrialized countries (United Nations, 1997). The Kyoto Protocol entered into force in 2005.

Prior to that, in 1996, the ISO 14001 was first published, providing international standards for environmental management systems for any organization (Von Zharen, 1996). Recently, the Intergovernmental Panel on Climate Change (IPCC) stated in its assessment report that "… changes in atmospheric concentrations of GHGs and aerosols, land cover and solar radiation alter the energy balance of the climate system…" and concluded that "… increases in anthropogenic GHG concentrations is very likely to have caused most of the increases in global average temperatures since the mid-20th century" (IPCC, 2007).

In order to gauge the GHG emissions of various human activities in an easy to comprehend and easy to compare fashion, the term Carbon Footprint has become very popular (Safire, 2008). Several definitions of the term Carbon Footprint have been put forward. One such definition has evolved out of other definitions of the past decades and

defines the Carbon Footprint as: "… a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product" (Wiedmann and Minx, 2007).

In this paper, we will rely on the aforementioned description of Carbon Footprint as a guide for evaluating various research efforts. It is because of our belief that this definition considers the commonly accepted accounting principles and modeling approaches. Furthermore, we concur that this definition of Carbon Footprint takes into account most, if not all, direct and indirect harmful emissions, caused by the activities of governments, businesses, organizations, and consumers (Ahmad, 2009). In the next section, we discuss the significance of E-Commerce Carbon Footprinting in our contemporary world.

A CASE FOR E-COMMERCE CARBON FOOTPRINTING

With the devastating potential of the climate change higher up on agenda around the world, the Carbon Footprint is now a buzzword that is extensively employed by the governments, businesses, and consumers around the world. The premise is that once governments and businesses know the magnitude of the Carbon Footprint of various activities, it is possible to formulate policies and strategies for reducing the overall emissions of GHGs (Ahmad and Bliemel, 2009; Wiedmann and Minx, 2007). Indeed, many in both the public and the corporate sectors have started calling for Carbon Footprint calculations for products or services provided to them. It is analogous to providing information on ingredients and nutritional contents of food products, as mandated by law in most countries (Ahmad and Bliemel, 2009).

Knowing the Carbon Footprint of various supply chains should enable businesses to develop policies for promoting Green Supply Chains in order to reduce environmentally devastating effects of GHGs. As mentioned, we believe that a great opportunity is being offered by E-Commerce towards achieving this goal of reducing carbon emissions (Ahmad and Bliemel, 2009). Despite differing views on how to measure the environmental performance, various studies strongly advocate the adoption of Eco-Efficacy and Eco-Efficiency for measuring and comparing the ecological performance of various supply chains (Abukhader, 2008; Abukhader and Jönson, 2004a). In short, the premise is that we need to improve Eco-Efficiency and Eco-Efficacy in operational activities in order to achieve greener supply chains. By making technical and strategic choices on ecological product design, production processes, scheduling, as well as both forward and reverse e-logistics, we may very well achieve our goal of improving Eco-Efficiency and Eco-Efficacy. Once again, achieving this objective requires reliably measurements and comparisons of the Carbon Footprints for various activities.

As mentioned earlier, a significant development in recent times, which may help improve Eco-Efficacy, is the emergence of the Internet-based economy (Ahmad and Bliemel, 2009). We are fast moving towards an Internet-based society and the Internet has managed to expand exponentially since its commercial inception in 1988 (Castells, 2001). For instance, in 2006, the worldwide number of the Internet users was 1.2 billion and projected to reach the 2 billion users mark by the year 2012, exhibiting a growth rate between 140 million to 145 million users per year. A growing population, more affordable and faster computers, and increase usage of mobile devices are considered main contributors to this astounding growth in Internet users (Turban et al., 2008). Moreover, it

is expected that the digital economy will be attained through the economic growth driven by Information Technology and E-Commerce. Based on these trends, the U.S. Department of Commerce began a discussion about the emergence of the digital economy (Henry, Cooke and Montes, 1998; Henry et al., 1999). Consequently, the future of the digital economy and the E-Commerce is promising even after considering the effects of the current economic downturn.

The trend is most certainly having shoppers move towards online shopping due to convenience, disintermediation, lower prices, and an ability to do quick comparison of product prices and features (Forrester, 2008). Indeed, online retailing is growing tremendously worldwide. According to a market research company, US online retail reached US$175 billion in 2007 and is projected to grow to US$335 billion by 2012 (Forrester, 2008). Canadian online retail reached US$12.9 billion in 2007 and is projected to grow to US$22.2 billion by 2012 (eMarketer, 2008).

Due to the importance of E-Commerce, various research groups are studying its environmental impact in relation to greenhouse carbon dioxide equivalent emissions caused by transportation, power consumption, and packaging. This survey paper is an attempt to facilitate the research in Carbon Footprinting of E-Commerce. In the next section, we provide a comprehensive literature survey as well as a framework for classifying research in this area.

LITERATURE SURVEY

There is a fast growing body of literature in this domain appearing in various journals, proceedings, and other knowledge repositories. However, the diverse perspectives and scattered locations of this literature mean that there is a growing need for an integrative literature survey. Such a survey will help guide researchers who are working on expanding the current literature.

In addition to an integrative literature survey, there is a need for classifying and cataloging the current diverse literature. In this regard, Abukhader and Jönson, (2003), provide one classification framework in a seminal study. However, the scheme is more appropriate for a rich and large body of literature despite of all its attributes. As such, it may not be suitable to the current body of relatively modest, albeit rapidly expanding, research. Consequently, we deem that a simpler categorization of research in this area is more suitable to the current body of literature. Indeed, the two dominant streams of research, namely Qualitative and Quantitative, provide a suitable categorization guides. In the following subsections, we provide a survey of existing literature with this notion in perspective.

Qualitative studies

Qualitative studies bear the character of largely subjective comparisons of Carbon Footprints in various E-Commerce activities. Among the various qualitative studies, some examine the theoretical and conceptual levels of the relationship between information society, sustainable development, and technology issues (Jokinen, Malaska and Kaivo-oja, 1998). Others studies advocate the need for quantifying the environmental footprint of the ICT systems on products and operations (Shah et al.,

2009). One study reflected on a critical survey on the topic E-Commerce and Environment. In that study, researchers attempted to define E-Commerce and classify the environmental effects, and eventually suggested a framework for future investigation (Abukhader and Jönson, 2003).

In recent times, there have been some studies on economic and environmental benefits of the Internet, which is the underlying infrastructure for E-Commerce. For instance, some inquires studied environmental and social aspects of E-Commerce (Rejeski, 2002; Türk, 2003). In addition, other studies considered the economic impacts of E-Commerce in their study (Yi and Thomas, 2006). One piece of literature listed several research papers that dealt with the environmental impact of e-business and Information Communication Technology (ICT) (Yi and Thomas, 2007). Rejeski (1999) analyzed the environmental effects of E-Commerce in the society and discussed the lack of regulations in E-Commerce at that time.

Such trends as the use of environmental regulations, policies, environmental literacy and Eco-friendly "bots or robots" were pointed out as positive signs (Sarkis, Meade and Talluri, 2002). Such bots are artificial intelligence programs designed to find on the Internet, especially in the E-Commerce sites, the most useful mixture of environmental aspects and price for any merchandise and service. In this regard, several experts searched the environmental effects of the forward and reverse cycle for e-logistics (Ibid.).

Some researchers reflected on the opportunities for the ICT industry to reach sustainability. It can be done by using: a) Smart motor systems by optimizing motors and industrial automation; b) Smart logistics by efficient transportation and storage; c) Smart buildings by improving design, automation and management; d) Smart grids by optimizing the monitoring and management of electricity grids, and integrating ICT systems into the energy Internet (The Climate Group, 2008).

Cohen (1999) predicted ten Internet trends that might likely become green practices and policies on the Internet to reach an ecologically sustainable society. Those are: “Mass customization” for Eco-Efficiency, marketing by pixels instead of packages, dematerialization of products, the de-malling of America, letting the modem do the driving, closing the loop on-line, green bot.com, reusing materials through on-line auctions, adding information to products for environmental efficiency, and globalization E-Commerce. Another research investigated the environmental effects of the Internet economy that were caused by IT infrastructure, Internet use, and its rebound effects (Fichter, 2001). One researcher analyzed the environmental effects of E-Commerce by using past works and by interviewing seven British companies. It was concluded with a recommendation that the businesses should consider the environmental aspects such as energy, transportation, carbon trading, and green products (Hurst, 2001). Similarly the others suggested that E-Commerce oriented businesses should pay attention on the resources that are used by logistics, inventory, and distribution (Thornton and Ferrone, 2001).

Naturally, researchers have been exploring the relation between the environmental effects of E-Commerce and logistic industry (Hultkrantz and Lumsden, 2001). Some reported on positive influences of E-Commerce on Sustainability of distribution systems

(Hesse, 2002). Consequently, important environmental and political strategies were suggested to achieve a sustainable society by reducing CO_2 emissions and energy consumption by increasing the IT and E-Commerce usage (Fichter, 2001). In addition, not only the energy and economic effects of E-Commerce were analyzed but also some business strategies were recommended in order to achieve sustainable development (Fichter, 2002). Moreover, several past studies were cited to support the argument that E-Commerce was inherently neither friendly nor hostile to the environment, thus here is no determinism.

Peng, Li and Zhang (2005) described a conceptual model followed by the discussion on positive and negative environmental effects of E-Commerce. Energy and resource savings were listed as positive impacts of E-Commerce; nevertheless, it was pointed out that E-Commerce also has its negative effects on the environment (Ibid.). Sui and Rejeski (2002) commented on other categorization of positive influences called the three D's - Dematerialization, Decarbonization and Demobilization. Also they stressed the significance of environmental policies in the information age (Sui and Rejeski, 2002).

Some researchers dealt with the financial and environmental effects of inventory management as well as the tradeoff between transportation and warehousing in a logistic network scenario (Matthews, Hendrickson and Lave, 2002). The analysis summed up that reductions in energy usage, resources and environmental emissions will be achieved by applying the E-Commerce model, which considers centralized inventory and shipping services (Ibid.). Other researchers concluded that, in logistics and transportation, concrete local contributions such as consumer habits, delivery modes, and population density contribute to distribution efficiency (Jönson, Orremo and Wallin, 2000; Davis, 2000; Koomey, 2000; Türk, 2003; Williams, 1999).

Romm (2002) outlined the impacts in the Internet Economy on facilities, production, transportation, energy consumption, etc. along with the environmental and economic effects of the Internet Economy itself in the USA. Furthermore, it was argued that the reduction in energy intensity is related with the growth of IT and Internet economy, which increased efficiency in the processes and required less energy than traditional methods. In short, it was argued that the Internet Economy is more likely to be environment friendly, cost-efficient, and energy-efficient than the traditional economy (Romm, 2002; Romm, Rosenfeld and Herrmann, 1999).

Abukhader examined the environmental implications of E-Commerce in a collection of four journal papers. This first paper is a literature review of the works that have been undertaken in the field of E-Commerce and environment as well as a framework for classifying future studies (Abukhader, 2003). Subsequently a two-dimensional environmental assessment model for green E-Commerce supply chains is proposed (Abukhader and Jönson, 2004a). Furthermore, the adoption of the Eco-efficacy approach as a complement to the Eco-Efficiency is proposed in order to examine the environmental consequences of E-Commerce. This proposal has its roots in the use of tools of efficiency and effectiveness for measuring the performance in a supply chain management system (Abukhader, 2008). Subsequently, the effects of logistics and supply chain management on the environment are explored from Sustainability perspective (Abukhader and Jönson, 2004b). In this regard, Amato-McCoy (2009) provided the analysis to reach Sustainability via ecological E-Commerce through a

comparison of trends in various metrics/indicators.

In Table-1, we summarize a list of some important Qualitative studies in E-Commerce Carbon Footprinting.

Table-1: E-Commerce versus Carbon Footprinting: Qualitative studies

Qualitative Studies on E-Commerce Carbon Footprinting
Abukhader, 2003, 2008; Abukhader and Jönson, 2003, 2004a, 2004b; Ahmad, 2009; Ahmad and Bliemel, 2009; Amato-McCoy, 2009; Brynjolfsson and Smith, 2000; Cohen, 1999; Davis, 2000; Fichter, 2001, 2002; Henry, Cooke and Montes, 1998; Henry et al., 1999; Hesse, 2002; Hulkrantz and Lumsden, 2001; Hurst, 2001; Jokinen, Malaska and Kaivo-oja, 1998; Jönson, Orremo and Wallin, 2000; Keeney, 1999; Klöpffer, 2008; Koomey, 2000; Matthews, Hendrickson and Lave, 2002; Peng, Li and Zhang, 2005; Rejeski, 1999, 2002; Romm, 2002; Romm, Rosenfeld and Herrmann, 1999; Sarkis, Meade and Talluri, 2002; Shah et al., 2009; Sui and Rejeski, 2002; Thornton and Ferrone, 2001; The Climate Group, 2008; Türk, 2003; Williams, 1999; Yi and Thomas, 2006, 2007

Quantitative Studies

Quantitative studies provide numerical figures and calculations for Carbon Footprint. A detailed study of enquiry in quantitative field demonstrates that the research in this area can be divided into three broad categories, namely products, services and tools. In the following we provide the survey of research in various product and service areas.

Books/DVDs

Some researchers explained the environmental effects of E-Commerce in regards to selling and buying books and DVDs. Matthews, Hendrickson and Lave (2000) compared Amazon.com and Federal Express E-Commerce supply chain efficiency while delivering about a quarter of a million copies of a popular fiction book to customers in the USA. Matthews and Hendrickson (2001) explained the economic and environmental impacts in generic scenarios for E-Commerce and traditional retailing for a single commodity, namely a best-selling book. The inquiry identified certain important determinants and drivers of environment friendliness and cost-efficiency such as shipping distances, return rates, or shopping allocations. It was concluded that the E-Commerce method is more environment-friendly and cost-efficient compared to traditional retailing (Matthews and Hendrickson, 2001). In another study, a generic scenario was created to compare the environmental impacts and monetary costs between the retail logistics and E-Commerce for a best-selling book. After considering several variables such as shipping distances, shopping allocations, return rates, unsold book returns, type of delivery, etc. the researchers concluded that E-Commerce was more cost-efficient and eco-efficient than the traditional retailing. Nevertheless, it was showed that where a book is not returned both delivery methods seemed to have comparable costs (Matthews, Hendrickson and Soh, 2001a, 2001b). To conclude, several papers were upgraded and restated (Hendrickson, Lave and Matthews, 2006; Matthews, Hendrickson and Soh, 2001a, 2001b).

Matthews et al. (2002) explained the financial and ecological impacts of traditional retailing and online retailing of books (single commodity) in generic scenarios for the USA and Japan. This study exploited two life cycle assessment models and hence compared the online versus offline retailing logistic systems. The result of the analysis

was that the energy and cost efficiency of the systems depend on the conditions of the implementations, especially the transport modes, shipping distances, population density, packaging, number of items per order, return rates or shopping purchase allocations used by suppliers and consumers (Matthews et al., 2002).

Reichling and Otto (2002) elucidated the environmental impacts of e-retailing versus traditional retailing for a book purchasing scenario. They observed that the environmental effects are correlated with the customer's commutating method. Williams (2002) compared online and offline retail for books in Japan and showed that E-Commerce has a slightly bigger Carbon Footprint than traditional retailing due to the need for additional packing. Moreover, it was pointed that the energy use in bookstores is comparable to the energy used at home when a consumer makes an online purchase (Williams, 2002). It was concluded that such important factors as transport modes, shipping distances, population density, packaging, number of items per order, return rates or shopping purchase allocations used by suppliers and consumers, etc. have impact on the energy and cost efficiency of the systems (Williams, 2002).

Williams and Tagami (2003) studied the environmental impacts of E-Commerce and the traditional retailing based on energy consumptions for the Japanese book market. One study searched for a design and evaluation of a sustainable networked delivery system for books in the USA. For this inquiry, they compared the emissions and energy consumption of three book delivery systems, which are the sustainable, networked delivery (SND), the traditional networked delivery (TND), and the E-Commerce networked delivery (END). It concluded that the best option is the SND system, which is a combination of E-Commerce system and pickup points or hybrid B2C book delivery (Kim et al., 2008, 2009).

Xu et al. (2009) used an Agent Based Modeling (ABM) technique to work on the market dynamics and environmental effects of buying books under certain logistic systems. Based on the energy and emission savings, it was confirmed that the use of a combination of E-Commerce and pickup points was a better option (Kim et al., 2008, 2009). Others commented about dematerialization caused by digital media and associated hardware regarding digital music delivery and concluded that digital formats do not beneficially contribute to dematerialization, largely due to increases in hardware (Hogg and Jackson, 2008).

Computers and Accessories

Caudill et al. (2000) analyzed the environmental impact of E-Commerce versus traditional retail for desktop computers. They reflected on two scenarios, the B2C scenario and an integrated B2B and B2C scenario through the use of web services. They applied the environmental life cycle analysis of the product to compare the two business models in the two scenarios. It was suggested that resources, energy and environmental burdens depend on the type of transportation used for distribution, especially in B2C scenario. However, if B2C is combined with B2B, the transportation type is not so crucial to have positive results (Caudill et al., 2000).

Other investigators explored ways to optimize an E-Commerce supply chain of desktop computers by employing fuzzy logic decision theory (Luo, Wirojanagud and Caudill,

2001).Others compared the energy consumption of e-retailing and traditional retailing of personal computers in Netherlands. Using a life cycle analysis it concluded that the energy use per article sold by the online reseller consumes less energy (Reijnders and Hoogeveen, 2001).

Gay et al. (2005) elucidated the environmental impacts of E-Commerce with regards to traditional retailing of personal computers in the USA. They recommended using more than one life cycle assessment software for the environmental analysis. The study demonstrated that E-Commerce was more environmentally beneficial to the world than the traditional method of purchasing and delivery (Ibid.). Weber et al. (2008) compared the energy consumption and carbon dioxide emission of E-Commerce and traditional retail. The unit of study was a flash memory and it exploited a data set from Buy.com in the USA.

Groceries

Several researchers studied E-Commerce in relation to grocery shopping. For instance, Cairns (1999) contrasted traditional versus electronic grocery shopping by focusing on B2C E-Commerce. Whereas, Li (2000) compared the economic and environmental effects of e-grocery home delivery models with the conventional delivery system in Lund, Sweden, indicating that the E-Commerce model seemed to be more efficient than the traditional model.

Persson et al. (2001) reported the design of energy-efficient and environmental friendly distribution network system for e-grocery in Stockholm in Sweden. Punakivi and Holmström (2001) also dealt with grocery shopping online. Siikavirta et al. (2003) explored the economic and environmental effects of e-grocery home delivery models, showing it as more environmentally friendly model in comparison to the conventional delivery system in Helsinki, Finland. Tehrani and Karbassi (2005) assessed the energy consumption and environmental impacts of e-grocery and conventional model for Tehran, Iran. Once again, the outcomes showed that the E-Commerce version was more environment-friendly and energy-efficient than the traditional model.

Advertising

Some researchers described a model to estimate emissions and energy consumption in order to deliver either online advertising or a given amount of information to an online user. The model assesses the energy use and data flows of the equipments inside the Internet Backbone, WAN (Wide Area Network), businesses' LAN (Local Area Network), PTN (Public Telephone Network), Cell sites, and excludes home network equipment, personal computers and wireless devices (Taylor and Koomey, 2008).

DVD Rental

A study focused on a comparative assessment of energy, environmental and economic impacts of online and offline DVD rental services. The analysis was performed using process-based and input-output life-cycle assessment methods. The data illustrated that the E-Commerce option has a better performance in terms of energy, environmental, and economic standpoints than the traditional DVD rental service (Sivaraman et al., 2007).

Information Delivery

Some researchers compared the environmental effects of two wireless technologies applications with their traditional versions for which they could substitute. The first comparison was between reading newspapers content by using a personal digital assistant (PDA) against the hardcopy version of a newspaper. The second was wireless teleconferencing versus business travel. Having had applied a life-cycle assessment, the data demonstrated that both wireless technologies produce lower emissions than the conventional technologies (Toffel and Horvath, 2004).

Carbon Footprint Calculators

Recently consumers have started to become more conscious about their Carbon Footprint by using online Carbon Footprint calculators. One investigator reported several Carbon Footprints calculators in use at the web at this moment (Dodge, 2008). Others compared various Carbon Footprint calculators, and concluded that although these calculators can estimate the personal Carbon Footprint, there is a lack of consistency between them as much as several metric tons per annum per individual and suggest developers to reach standardization of this assessment tool. Clearly, there is a need for more formal and elaborate quantitative models for this purpose (Padgett et al., 2008).

In Table-2, we summarize a list of some important Quantitative studies in E-Commerce Carbon Footprinting.

Table-2: E-Commerce versus Carbon Footprinting: Quantitative studies

<table>
<tr><th colspan="4">Qualitative Studies on E-Commerce Carbon Footprinting</th></tr>
<tr><td colspan="4">Products</td></tr>
<tr><td>Books/DVDs</td><td colspan="2">Computer and Accessories</td><td>Groceries</td></tr>
<tr><td>Hendrickson, Lave and Matthews, 2006; Hogg and Jackson, 2008; Kim et al., 2008, 2009; Matthews and Hendrickson, 2001; Matthews, Hendrickson and Lave, 2000; Matthews, Hendrickson and Soh, 2001a, 2001b; Matthews et al., 2002; Reichling and Otto, 2002;Williams, 2002; Williams and Tagami, 2003; Xu et al., 2009</td><td colspan="2">Caudill, et al. 2000; Gay et al., 2005; Luo, Wirojanagud and Caudill, 2001; Reijnders and Hoogeveen, 2001; Weber et al., 2008</td><td>Cairns, 1999; Li, 2000; Persson et al., 2001; Punakivi and Holmström, 2001; Siikavirta et al., 2003; Tehrani and Karbassi, 2005</td></tr>
<tr><td colspan="4">Services</td></tr>
<tr><td>Advertising</td><td>DVD Rental</td><td colspan="2">Information Delivery</td></tr>
<tr><td>Taylor and Koomey, 2008</td><td>Sivaraman, et al., 2007</td><td colspan="2">Toffel and Horvath, 2004</td></tr>
<tr><td colspan="4">Tools</td></tr>
<tr><td colspan="4">Carbon Footprint Calculators</td></tr>
<tr><td colspan="4">Dodge, 2008; Padgett et al., 2008</td></tr>
</table>

FUTURE RESEARCH DIRECTIONS

In order to advance the research in Carbon Footprinting, identification of some of the

critical aspects of supply chains for appraisal and modeling would be essential. Clearly, there are some aspects of supply chains that cannot be meaningfully identified as critical or non-critical based only on the available scientific data. Consequently, some qualitative approaches would be helpful in identifying those aspects of the supply chains that are critical to achieving the environmental Sustainability objective. Once critical aspects of both E-commerce and traditional supply chains are identified, quantitative approaches would be required to model those aspects in form of reliable, reusable, and extendable mathematical models and formulae (Ahmad, 2009). More specifically, it would require extensive mathematical modeling of complex, non-linear, interdependent supply chain dynamics (Ahmad, 1997). Such quantitative model would be beneficial in developing effective, interactive, and adaptive decision support systems for policymakers, business managers, and researchers (Ahmad, 2005).

The existing research in this domain has largely dealt with assessing Carbon Footprinting for such products as books, DVDs, groceries, electronics (computers), etc. as well as such services as printing, advertising, and DVD rental. In future, we suggest an increased focus on Carbon Footprint of various services, for instance pharmaceutical services and online education. In addition, there is a need to assess cost of various potentially adverse social implications of E-Commerce such as reduced social interaction, reduced physical work, etc. (Ahmad, 2009). Moreover, there is a need for extending the existing Carbon Footprinting calculators to create usable and effective Decision Support Systems (DSS). Various integrated decision models for E-Commerce supply chains may prove useful in developing such DSS. Indeed, such DSS have been effective in various complex interdisciplinary problem solutions and the promise of using DSS in this complex domain cannot be overemphasized (Ahmad et al., 2008a).

Furthermore, the intricate interdependency of complementary and substitute products and services mean that no meaningful Carbon Footprint assessment can be done by focusing on merely a single product or service in isolation. There is a need to take an integrative look at the supply chains of complementary and substitute products as well as product families, too. Naturally, there is growing need for developing integrated quantitative decision models (Ahmad, 1997; Ben-Daya and Rahim, 1999; Ben-Daya and Rahim, 2003).

We would like to emphasize that the scope and complexity of these research directions would require significant support from governments, regulatory bodies, and research institutions. Furthermore, it would require interdisciplinary research teams with skills in such diverse domains as Operations Research, Management Sciences, Supply Chain Management, Marketing, Environmental Management, Social Sciences, Strategy and Policy, etc. As suggested earlier, an integrative systems approach to such a broad-ranging problem is needed (Ahmad et al., 2008b). For instance, the Carbon Footprint of the entire communications and computing infrastructure developed to enable high-speed data transfer including end-user computers, servers, routers, and communications channels are ignored in past studies on E-Commerce Carbon Footprinting. Nevertheless, the true life cycle analysis should take into account the environmental impact of environmental impact of the entire enabling and supporting infrastructure of E-Commerce.

SUMMARY

This paper provides an extensive literature review of significant contributions to the research in Carbon Footprinting of E-Commerce. It not only complements the past literatures surveys in this critical research area but also classifies the relevant literature in two broad categories, namely quantitative and qualitative studies. Within the quantitative category, we have further categorized literature based on products, services or tools considered for measuring Carbon Footprinting in those papers. Consequently, this review not only brings a novelty in scope but also contributes to the research on E-Commerce and Carbon Footprinting in terms of updating the relevant information. Moreover, the classification framework presented in this paper may prove useful for future literature surveys. We have also provided some novel and interesting future research directions. This paper will be useful to government and corporate policy-makers as well as environmentally conscious consumers. We believe, this paper contributes significantly to the existing literature by providing a useful resource to all those interested in using or pursuing the research in this area.

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