From Paper to Pixels

Evaluating the Impacts of an Industrial Transition

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Executive Summary

The landscape of print media consumption is changing. Paper and its iterations, books, magazines, newspapers, are shifting in the marketplace. Digital media is taking hold as a substitute. Computers, E-Readers, smartphones and other electronic devices are providing a new format for the printed word. Many see this transition as a boon for the environment. But, is it?

Concurrent to this industrial transition is the growing interest in the concept of sustainability. The coalescence of diverse groups from across the social spectrum around the idea of sustainability makes the application of this concept to the paper to digital media transition important. If the world were indeed serious about being green, we would be well served to apply ourselves to the current paper to pixel (P2P) transition. And so we ask, is the P2P transition taking us in a sustainable direction? This report will not attempt to answer this question directly; rather it attempts to provide a framework for analysis.

We deliberately chose not to restrict our research to what is often referred to as the functional unit, for example, a newspaper or a smartphone. There are simply too many changing and complex variables to allow for a very robust comparison and we believe its utility is limited.

We consider the P2P transition through the prism of industrial ecology, identifying benchmarks that define a sustainable industrial system. Each of these benchmarks reflects the intersection of three things: the complexity of the P2P transition; the strengths and weaknesses of existing P2P analyses; and the linkage to industrial ecology. We use these benchmarks to guide our analysis of the supply chains in Forestry and IT.

Against this background we chose to set the objectives of this report as follows: 1. Summarize our survey results of paper and digital consumers in North America. 2. Review seminal ideas that can contribute to an analytical framework and then

develop a framework to help interested parties debate the merits of Paper and Pixel.
3. Review and analyze the supply chains of both paper and digital media.

Our survey shows that while there is a perceived shift from papers to pixels, however, paper media still has a strong relationship with the marketplace. Consumers are willing to pay for paper media, find it an effective and credible source, and in certain product categories, indicate that they will continue to consumer paper media even in light of digital alternatives.

The review of existing literature that compares paper and digital media indicates that traditional tools, such as LCA, are not necessarily well equipped to answer questions about the environmental trade-offs between paper and pixels.

After gauging the potential of IT and Forestry against the benchmarks established in industrial ecology, we illustrate how each sector can improve the environmental performance of the media it delivers. It's clear that the best case scenario in each industry is dependent on several things: a transparent and measured supply chain; research and development of new technologies to avoid hazardous materials and waste streams; a robust end-of-life management strategy that recovers the value embodied in a product and avoids releasing hazardous waste into the biosphere; and an effort to identify and mitigate the variables that have most influenced the environmental burden of a media product. We find that forestry has the potential to be a self-sufficient and renewable industrial system, and that best-case scenarios that exist with today's technology and management are very "green" relative to the benchmarks of industrial ecology. IT, on the other hand, faces a greater challenge given its dependence on non-renewable resources, the pace of innovation and product replacement, and the difficulties associated with E-waste.

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1. Introduction and Rationale

The landscape of print media consumption is changing. Paper and its iterations, books, magazines, newspapers, are shifting in the marketplace. Digital media is taking hold as a substitute. Computers, E-Readers, smartphones and other electronic devices are providing a new format for the printed word. Many see this transition as a boon for the environment. Newspapers, with their short lifespan and complex transportation networks, may no longer be needed in a digital world. One E-Reader can contain the pages of a hundred books. In short, this new media landscape requires less paper. And with less paper comes a commensurate decrease in forestry operations. However, to consider this transition as inherently "green" is at best over-simplified, and perhaps even misleading. Many existing analyses that have come to the conclusion about the green benefits of a paperless world prefer to identify a single and discrete unit, such as a newspaper or book. Analyses that capture the environmental impacts of an entire industrial system are avoided; the analysts claim that the required scope is simply too large.

Concurrent to this industrial transition is the growing interest in the concept of sustainability. Sometimes a buzzword, or the cause of a dedicated advocate, or a sincere and robust effort by a company, country or organization, the concept of sustainability is enjoying increasing prevalence. At its most basic level, sustainability means that current economic activity should not compromise the well being of future generations (United Nations, 1987). The coalescence of the views of diverse groups from across the social spectrum around the idea of sustainability makes the application of this concept to the paper to digital media transition important. If the world were indeed serious about being green, we would be well served at applying our minds to current P2P transitions. And so we ask, is the P2P transition taking us in a sustainable direction? This report will not attempt to answer this question; rather it attempts to provide a guide for analysis. We must consider seriously what we mean by "sustainable". Further, we must look at an industrial transition not only from the obvious and quantifiable environmental impacts (for example, carbon emissions) but also from a long-term, systemic level.

To fully account for the environmental impacts of two distinct and complex industries (IT and Forestry) is perhaps impossible. We are aware of this, nonetheless, we try to capture the complexity, paradoxes and conundrums as best we can.

We want to provide insight on the intrinsic characteristics of these two unique industrial systems. Our approach to confine ourselves to examining a broader set of principles since they are useful to identify the pros and cons of a particular industrial system and they help describe areas for improvement. Where useful, we use illustrative examples to argue a particular point.

We did not easily conclude that the principle-based approach was the best. At first we hoped to define a functional unit of analysis, say a 400 word article, and see if we could measure the impacts of a paper or digital equivalent. However, when trying to establish the boundaries for such an analysis we quickly realized that we risked being slaves to our own assumptions. Did those 400 words appear on a desktop, a smartphone, an E-Reader? Were they printed on newspaper delivered to a suburban home with one occupant, or on a newspaper that spent its day on the seat of a bus, read by dozens of people? We concluded that trying to create a functional unit leads to narrow investigations, highly sensitive investigations, or some combination of the two.

We are certainly not dismissing the utility of well-scoped comparative analyses of paper to pixel transitions. Some excellent studies (see Moberg, 2009; Kozak, 2003; Enroth, 2009.) have already been produced. We felt, however, that there is a gap in knowledge at the systemic level. If our goal is to understand the impacts of an industrial transition (or as some might say, an industrial revolution), we have no choice but to remain at the conceptual level.

We found the ideas and concepts needed to assess this transition in the field of Industrial Ecology (IE). At its most basic level, IE suggests that industrial systems should be inspired by nature. In an ecological system, there is no waste, only byproducts. Such systems aren't just efficient but also effective: they don't minimize the bad, but instead natural processes actually do something useful or good. These are lofty ideals, but these are powerful concepts. Inside the field of IE, specific methodologies have been developed: Material Flow Analyses (MFA), Life Cycle Assessments (LCA), or Input-Output Analysis are all attempts at connecting human industry to ecological realities. Each of these approaches contributes to a series of principles that helps to define a sustainable industrial system.

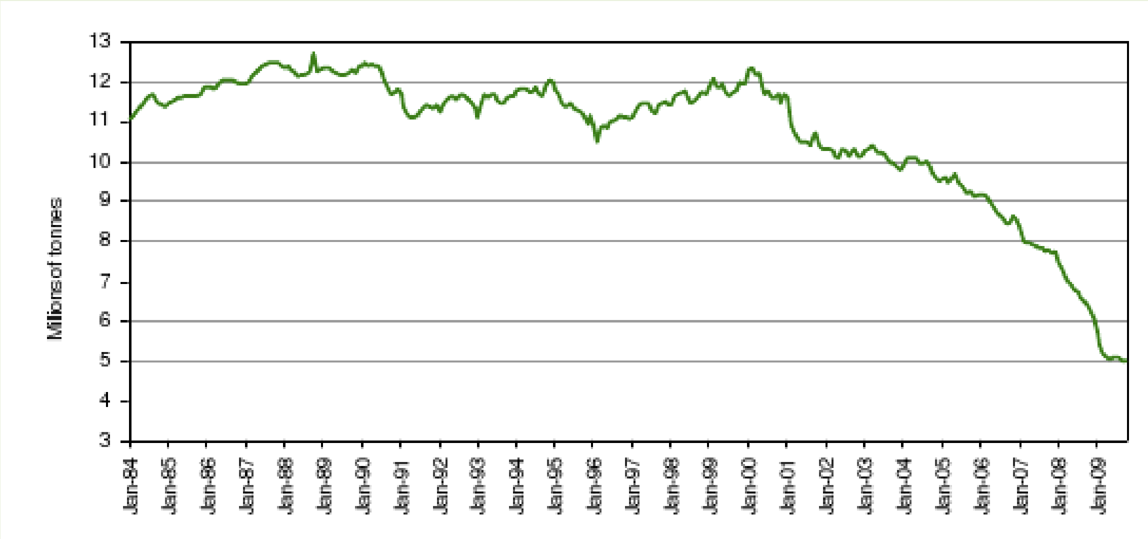
The objectives of this report then are threefold. First, it summarizes the results of a survey of 1400 paper and digital consumers in North America. Second, it reviews seminal ideas that can contribute to the development of a framework to help interested parties discuss the paper to pixel transition. Third, and finally, it reviews and analyzes the supply chains of both paper and digital media.

For the fourth objective we assess the environmental issues at five stages: raw material extraction, materials processing, manufacturing and assembly, distribution and consumption, and end-of-life. We adopted a scenario-based approach for several reasons. It allows us to explore what can be, rather than simply what is. It also allows us to identify the variables that can exert the most influence over the life cycle of a product. Finally, it means we can focus on the conceptual level and not be immediately burdened by the data requirements of a standard LCA approach.

2. Assessing the Transition

Describing the paper to pixel transition is not simple. There is such variety in the many transitions that no single metric that can capture the diversity in the scope, volume or intensity of the transition. Our goal is not to describe specific transition, but instead to consider the types of transitions. Given the diversity of media that can be consumed either on paper or digitally, this approach was necessary.

The complexity of the transition is simple to illustrate: media that previously could be consumed only on paper is now available on a vast array of digital devices. In some instances, the transition is swift. For example, the circulation of national newspapers in the United States has dropped (see Figure 1) while more readers go online. At the same time, small local daily newspapers have had a different experience – either their sales have held steady, declined by only a small margin, or increased. The transition affecting one segment of media cannot be assumed to extend to another, even if it is in the same category.



Reproduced from Roberts, 2009.

Figure 1: Total U.S. Newsprint Consumption (million tonnes)

There are three types of transitions that we think should shape any analysis. There are transitions from paper to digital products that have already begun or taken place. There are transitions from paper to digital products that are possible, given changing consumer habits and the availability of new technology. And finally, there are transitions from one paper media to another.

The diversity of paper based media and the diversity of digital alternatives warrants discussion. Paper media can be a newspaper, magazine, book, catalogue, flyer insert, directory, printing or writing paper, invoices and bills, etc. All of these serve as a basis for communicating information. Digital media is similarly equipped to communicate over a wide variety of platforms including desktop computers, laptops, internet-enabled cell phones, tablet computers, or E-Readers. With this many products and types of information, the scope for different transitions is vast.

Further, different demographics and different marketplaces will undergo unique transitions. For example, it should be recognized that developing and developed countries may not necessarily follow the same patterns. Although income levels can impact how much digital media a market can consume, developing markets may skip a step and not go through the same stages of paper media consumption.

There are also characteristics of media consumption that need to be considered when considering the paper to pixel transition. Media consumption is not necessarily a zero-sum game. If the marketplace consumes more digital media, it does not need to come at the expense of paper media. This is not to suggest that increased digital consumption does not impact paper consumption, it's just isn't necessarily a direct trade-off.

The transition towards digital media is not simply the result of consumers becoming tired of the offering provided on paper media. Digital devices are capable of providing a broad range of services, far beyond their ability to communicate what was previously on paper. For example, digital devices can email, bank, shop, play videos, take pictures and act as GPS devices– this multi-functionality is a large part of their attraction to consumers. And, most importantly, it also implies that the environmental impacts of digital devices are spread over multiple uses.

It is this complexity in the scale, degree and nature of the paper to pixel transition that frames our analysis. We deliberately avoid any specific scenario and simply posit – there is a transition, it is dynamic and uneven, and it's manifesting itself in many ways.

We are interested in this transition for several reasons. It has the potential to impact existing industrial assets (like the facilities needed to provide paper media) by reducing the demand for their products. It is also a determinant in what new industries and supply chains will appear, as factories that produce the components and products that support digital media are built. In either case, there is an environmental impact associated with shutting down and opening new facilities which leads to questions such as: What are the environmental implications of moving away from paper-based media? Or, what will more and more digital devices (and all the factories and resources necessary to produce them) mean for the environment?

3. Assessing the Marketplace

The perceptions of the marketplace are important in understanding the paper to pixel transition. Consumers are making decisions about how to consume media, as well as forming perceptions on issues of environmental concern. These decisions and perceptions will shape how the paper to pixel transition unfolds. Figure 2, depicting results from our own survey, shows that, with the exception of books from a library, respondents consumed more paper media five years ago than today, and expect to consume less paper media in five years from now. Further, it shows that less E-Media is consumed today than five years ago, and more consumption is antcipated five years from now.

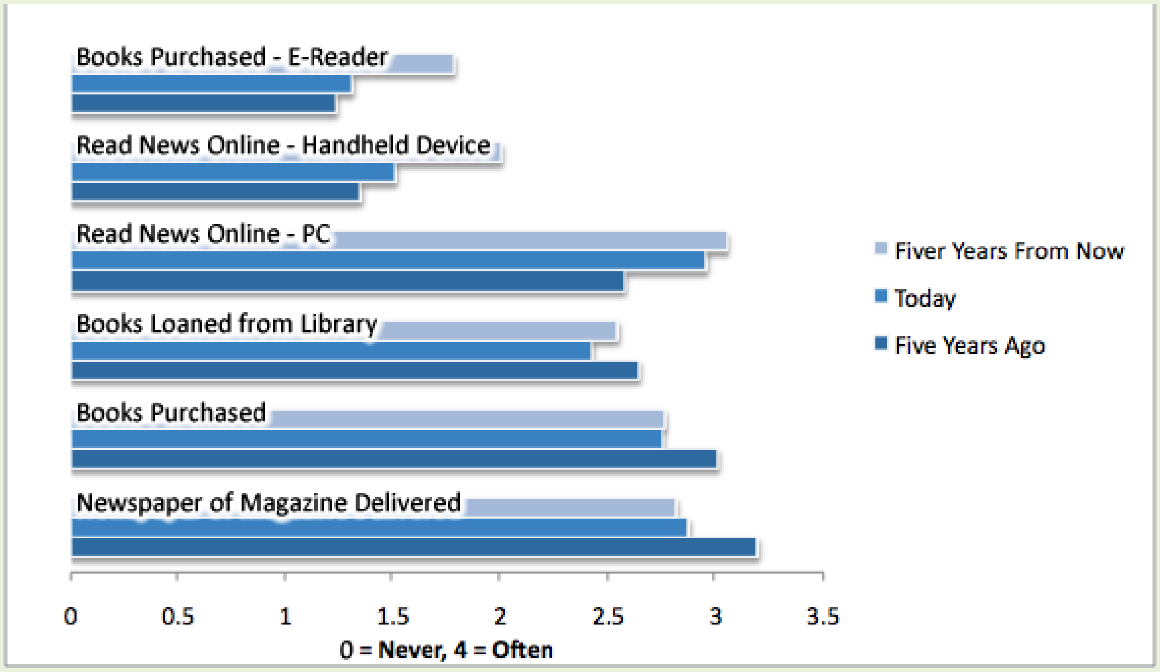


Figure 2: Change of Media Consumption Over Time

However, this transition has important nuances. Consumers still consider paper media to be a more credible source and a more effective form of advertising than any digital counterpart. Local newspapers are the most popular form of paper media, with over 66% of respondents saying they consume a local newspaper (books were the next highest category of paper media at 34%).

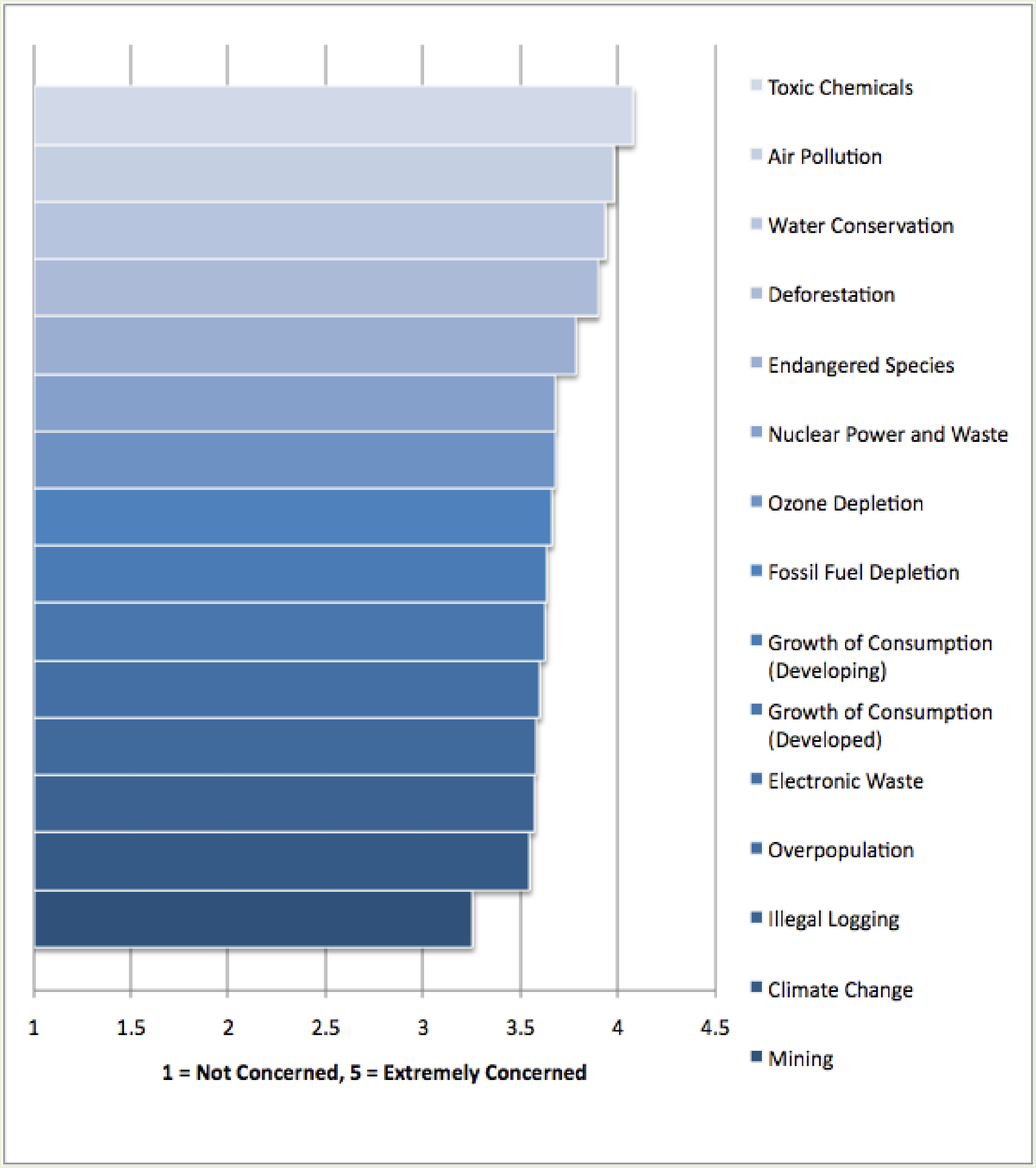


Figure 3: Ranking of Issues of Environmental Concern

Our respondents also showed that they use their electronic devices for a wide variety of purposes. This diversity in function is important when trying to establish a connection between the environmental burden of a device and E-Media. Reading news online was the fourth most common use of an electronic device, behind Email, Online Banking and Research. Consumers also suggested that they infrequently replaced their electronic devices. Cell phones, for example, were stated as being replace on average every 3.6 years. This response should be considered carefully, as most cell phone contracts last between 2 and 3 years, and on the completion of a contract consumers are offered a new cell phone for little or no cost.

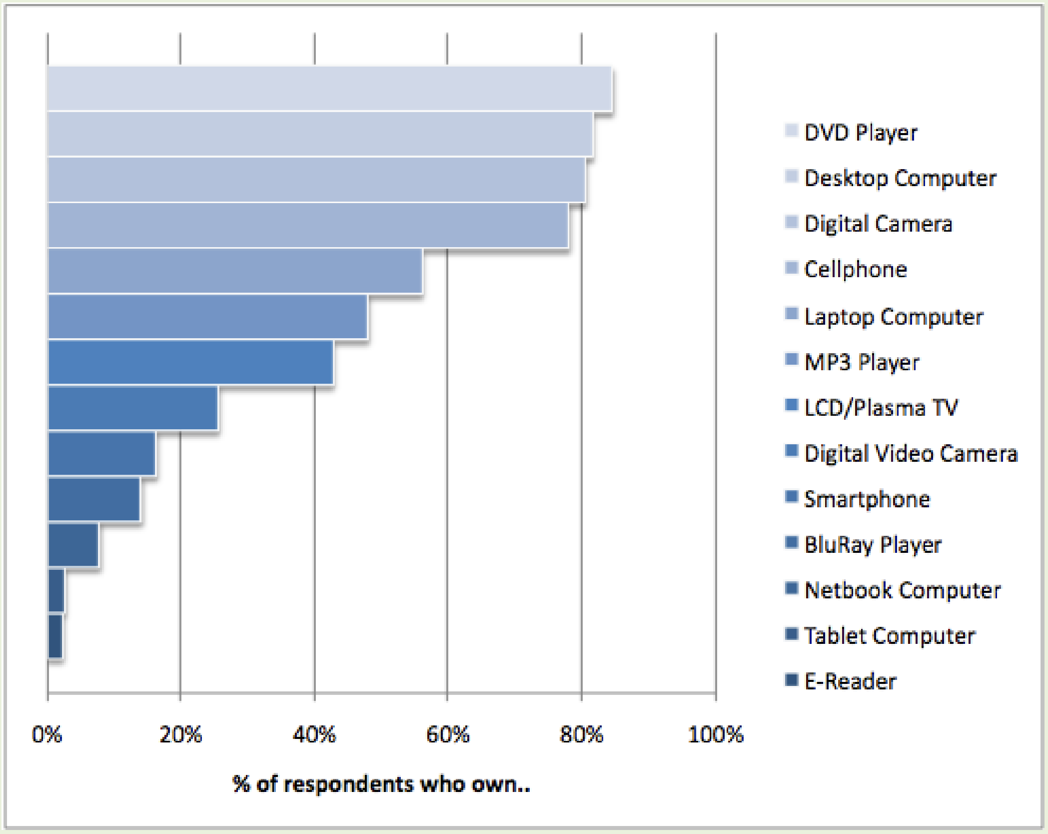


Figure 4: Technology Ownership

The three key conclusions of our survey: consumers expect the paper to pixel transition to continue; there are still areas where consumers prefer paper; and IT devices are used for much more than the consumption of E-Media. These conclusions inform the rest of our analysis. The complete results of the research survey are found in Annex 2.

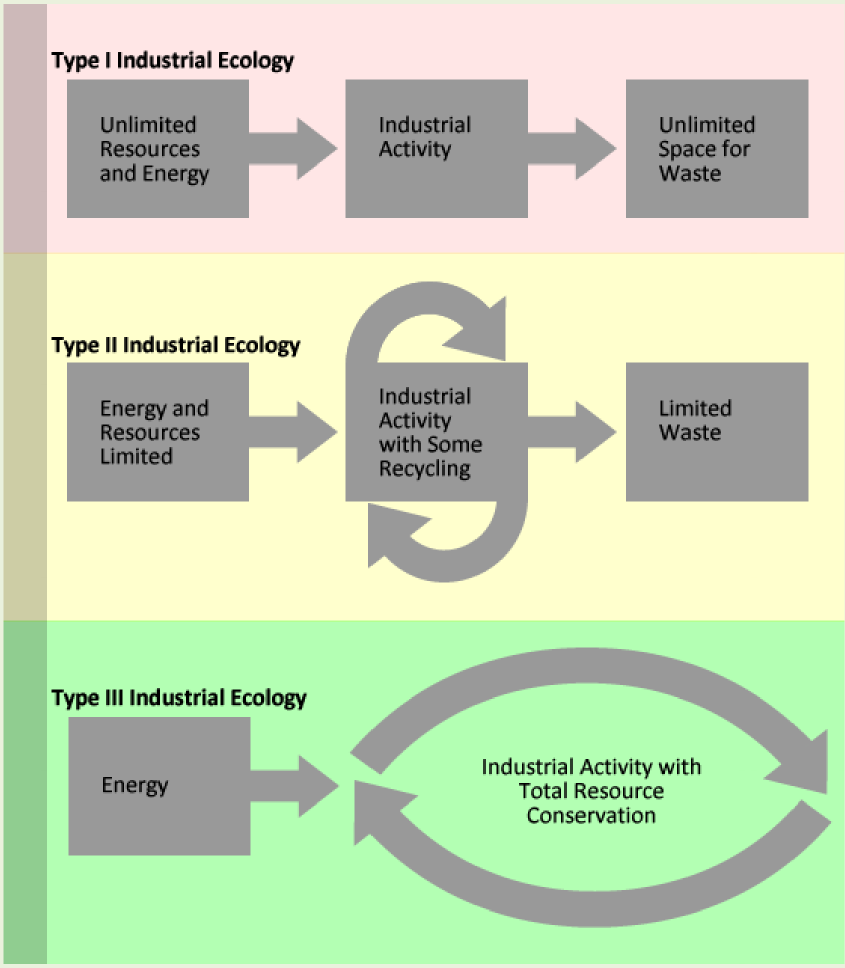
4. Reviewing Current Approaches

This report is by no means the first attempt to review the paper to pixel transition. Other studies have examined specific scenarios, like the shift from paper to electronic billing (Moberg 2009), or the move from paper textbooks to digital textbooks on a college campus (Kozak 2003). These very specific scenarios are important because they attempt to contrast the environmental impacts of paper and digital media. However, like all life cycle assessments (LCA), they are products of the boundary conditions of the analysis. While setting a boundary condition is a necessary and important part in the construction of an LCA (Schaltegger, 1996), it does have drawbacks. For example, the analysis might be constrained to versions of a life cycle that are arbitrarily shortened because of poor data availability.

In another example, the LCA approach could be dependent on the definition of a functional unit. Moberg (2009) uses the functional unit of one bill. She assumes that it is either delivered by mail, or viewed on the computer of a consumer. She is required to describe the transport distances to deliver by mail, a variable that can be highly sensitive given the range of possibilities in transport distances. She is also required to assume that a certain percentage of a digital products lifespan is used for the act of bill reading. This assumption can vary widely, as some consumers might use their computer for many years and only for bill reading; others might often replace their computer, but perform a wide variety of tasks, bill reading being only a small fraction of the machine's overall use. The variance implies that the environmental impacts of the digital device may be associated only with the act of bill reading, or they may be spread out over a wide variety of machine functions.

In short, the LCA approach requires such a specific set of conditions that it is not well suited to describing the impacts of an entire industrial transition. And given the complexity and scope of the paper to pixel transition, an analysis with boundary conditions and highly specific functional units can struggle to connect with the broader impacts of an industrial system. Constrained, contained, and bounded analyses can in fact draw conclusions that have tenuous, even erroneous, connections with the broader implications of an industrial activity. LCAs are by their very nature products of what can be measured. But in understanding a complex industrial transition, it could be argued that what cannot be measured is even more importance.

We considered other methodologies that have not yet been applied to the paper to pixel transition and found the most compelling approaches are in the field of Industrial Ecology (IE)(Erkman, 1997). As illustrated in Figure 5**,** the basic premise of IE is relatively simple: the systems of industry can be inspired by those found in nature. In both industry and the natural world, materials and energy flow between different actors. IE is the attempt at conceiving how industry might better mimic the patterns of nature, becoming more efficient, more effective, less wasteful, and overall, more sustainable.



Reproduced from Krones, 2007

Figure 5: Three Types of Industrial Ecology.

Graedel and Allenby (1995) grounded the idea of IE when they suggested that the maxim of IE be that "no molecule should enter a factory that does not leave as a saleable product". This approach has played an important and defining role in IE. In order to support this idea, scholars of IE have developed many tools to assess industrial behaviour. Material Flow Analysis (Ayres, R. & Ayres L. 2002.) follows the flows of elements through industrial systems, identifying the characteristics of these flows as well as opportunities for improvement. Input-Output Analysis (Ayres, R. & Ayres L. 2002.) is an effort at creating data tables for an industrial sector or facility, and measuring all of the inputs and outputs in order to determine the material-use rate, possible environmental impacts, and opportunities for creating connections between industrial actors.

There is a connection between the ideas of IE and the sustainable supply chain management concept of the closed loop supply chain. The closed loop is the effort to ensure that the design and composition of a supply chain and product are adjusted to ensure that all of the materials inside the supply chain are recaptured and reused (Beamon, B. ,1999).

Graedel also developed a tool called the Streamlined Life Cycle Assessment (SLCA) (Graedel & Howard-Grenville, 2005.). The SLCA takes a different approach to the construction of an LCA, and this is relevant to the problems of current paper to pixel analyses. The SLCA can be applied to products, processes or facilities. Applying the SLCA means breaking these three components of a life cycle into four categories of environmental concern: Energy, Water, Scarcity, and Hazard (EWSH). By assessing products, processes and facilities in these four categories, all of the environmental impacts are captured. The EWSH approach is pragmatic: it allows the findings of a study to be connected quickly to an environmental issue. For example, if excessive carbon emissions are a concern, then E in the EWSH matrix, will be the most informative.

Since SLCA does require the identification of a specific facility, process or product the challenges with analyzing the paper to pixel transition remain. In the case of digital media, the complexity and diversity in the facilities, processes and products limits the utility of SLCA for evaluating the paper to pixel transition. However, the SLCA and the EWSH matrix do help organize conceptual thinking.

The book *Cradle to Cradle* (McDonough and Braungart, 2003) also presents useful concepts when considering the impacts of an industrial transition. While not within the mainstream of academic IE, *Cradle to Cradle* provides additional ideas for improving industrial systems, efficiency, effectiveness and mproved product design.

For the authors, efficiency is simply an act of doing less bad – for example, using less water, less energy, emitting less of a pollutant, etc. Instead, the concept of effectiveness deals with another dimension of industrial systems – how an industry might facilitate the conversion of waste to energy, help clean a local water supply, or provide habitat remediation. Finally, product design must evolve if industrial systems are to excel at mimicking the properties of nature. Products that can be fully recycled at their end of life and be useful and valuable inputs into another life cycle are ideal.

How does this apply to our analysis? Take the pixel portion of the transition for example. The plastic in a computer case takes energy and water to produce, and harmful byproducts are released in the process. If at the end of life, that plastic can be recovered and used again in a similar application, then at least the embodied impacts are able to be spread out over a longer lifespan. If, however, at the end of life, recovering the plastic from a computer case is difficult or expensive, it may end up being reused in a less valuable way, or simply thrown out. Efficiency, effectiveness and product design all play an important role in new product development.

McDonough and Braungart also suggest that all products are a combination of biological and technological components or 'nutrients'. Biological components are derived entirely from natural sources and at their end of life can safely biodegrade back into the environment. Technological components are those that result from the extraction and processing of materials into something not naturally available. These materials do not biodegrade easily, and are often be associated with environmentally harmful pollutants. If a product or process is designed to ensure that the technological and biological nutrients can be separated at the end of life stage, then two things can happen: the value and environmental impacts embedded in the technological nutrients can be extended over additional life-cycles via upcycling; biological nutrients can either be reused by an industrial process or returned to nature, where they benignly degrade or even provide useful nutrients to natural systems.

Finally, McDonough and Braungart consider the concept of functional redundancy. With origins in evolutionary biology, functional redundancy is the idea that effective systems have the capacity to suit more than one purpose. Genetically, one of the main drivers of evolution has been massive redundancy in genetic stock (Gould, 1996), allowing life to evolve and sustain itself through enormous “flexibility, not admirable precision”. Applying the same idea to industrial facilities and product design is important in industrial transition. If a factory, for example, can adapt to produce another product or service, or if it’s waste is a valuable input in to another factory, or if it can produce multiple value streams simultaneously (such as energy generation and water purification in addition to a manufactured good), then that factory can be considered functionally redundant. Industrial systems that can be characterized by functional redundancy in facilities and manufactured products should be considered closely.

The foregoing studies do present ideas to better evaluate the paper to pixel transition but they are insufficient. If we are attempting to assess an entire industrial transition, paper to pixel, a different framework is needed.

5. Building a Framework

Evaluating the paper to pixel transition is complex. We have argued that the LCAs only apply to very specific trade-offs, not an industrial transition. The SLCA, sustainable supply chain management, cradle to cradle, and IE methodologies provide useful guidelines to our analytical framework; they are indeed necessary, but not sufficient when used in isolation. Our approach is inspired by these methodologies and we refer to it as the Supply Chain Assessment (SCA).

The SCA looks at the supply chain of an industry, and breaks it down in to five stages: Raw Material Acquisition, Materials Processing, Manufacturing and

Assembly, Distribution and Consumption, End of Life. It then mimics Graedel's SLCA approach and identifies concerns in four categories: Energy, Water, Scarcity and Hazard. However, instead of attempting to sort these variables inside a matrix, we use EWSH to help organize our analysis.

With these five stages, and four areas of concern, we can review the supply chains of paper and digital media, assessing environmental concerns and the inevitable trade-offs. We also feel that looking at the footprints of the platforms, products and processes needed to deliver media (i.e the hardware) is more important than the products and processes that deliver the actual media content (i.e. software). When it comes to the environmental implications of media, to borrow from Marshall MacLuhan, "the medium is the message". Further, digital and paper media often share the same content creation systems (i.e. the editorial offices of a newspaper can produce content that is available both on paper and digitally), so we decided not to examine the actual media content in our comparative analysis.

Our goal is to consider the qualitative and quantitative indicators for each stage in IT and Forestry focusing on issue of environmental concern. We attempt to use illustrative data to demonstrate how this approach to the paper to pixel transition can be supported with data collected from individual studies. However, given the sheer scale of products, process and variables considered, finding the appropriate amount of cost-effective data will be a challenge.

Further, data availability is a serious issue, particularly in the IT sector. Two things contribute to this: the number of different suppliers inside an IT supply chain makes it much more difficult to identify all the specific stages needed for measurement; and IT companies are less inclined to disclose data on their environmental footprints because specific disclosure might indirectly reveal information about industrial processes being employed.

The SCA evaluates the supply chains of the paper and pixel industries using the benchmarks extracted from the SLCA, supply chain management, cradle to cradle, and IE. These benchmarks are:

- **Closed loop**. Be capable of achieving a closed material loop, eliminating as much waste as possible, and recovering outputs to the greatest extent possible.
- **Embodied impacts**. Be capable of preserving the impact and value inside a product, and prioritize the reuse of components with significant embodied environmental impacts.
- **Renewable.** Be capable of using renewable, responsibly sourced raw materials whenever possible. And if non-renewable resources are not available, be capable of eliminating or minimizing the use of the most scare, toxic, or hazardous components.
- **Functional redundancy**. Be capable of building functional redundancy into products, processes and facilities.

Each of these benchmarks reflects the intersection of three things: the complexity of the paper to pixel transition; the strengths and weaknesses of existing paper to pixel analyses; and ideas in industrial ecology. We use these benchmarks to guide our analysis of the supply chains in Forestry and IT. Our goal is to identify the characteristics of a supply chain that can maximize potential to be sustainable. Through this process, we feel that the strengths and weakness of Forestry and IT can be better understood. Further, the paper to pixel transition can be seen in the light of not just specific markets and products, but as a part of an industrial transition.

Essentially the embodiment of these four benchmarks would take us to the type III industrial ecology highlighted in Figure 2. Most industrial systems are somewhere in the type I or type II ecology and we will describe where the paper and pixel industry is positioned using these benchmarks. We connect the ecology types of Figure 5 with the benchmarks in Figure 6.

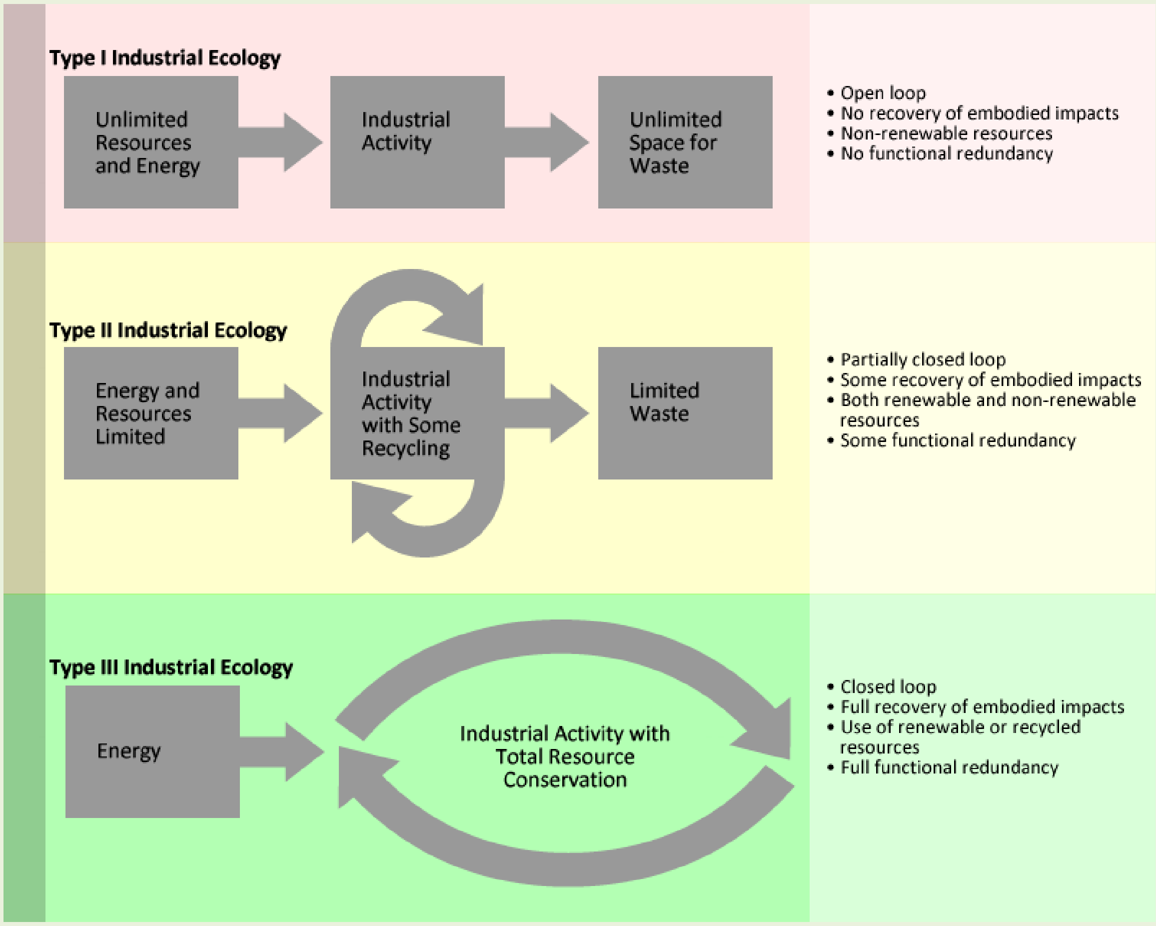


Figure 6: Ecology Types and Benchmarks

We have not designed our approach to suggest that paper is better than pixels. Instead, we want to identify where there is room for improvement, examine the key strengths and weaknesses of each sector, and consider IT and Forestry in the light of our benchmarks. This approach will help generate ideas about how the paper to pixel transition may continue, and how each industry may evolve as they face increasing pressure to be more sustainable.

6. The IT Sector and E-Media

We review here the five stages in the life cycle of an IT product. We identify EWSH risks, as well as consider how each stage can contribute to overall environmental impact of a product. However, we begin with an overview of the challenges IT faces and the necessary context to ground our analyses of the IT supply chain that delivers E-Media.

Moore's Law, first stated by the founder of Intel, Donald E. Moore, suggests that the number of transistors on a circuit board will roughly double every two years. This exponential growth has yet to be proven incorrect (see Figure 9 in Annex 1: IT Information), and is one of the defining characteristics of the IT sector. Moore's law has extended beyond transistors on a circuit board to other components as well: processing speed, memory, and storage capacity in IT devices have all experienced a similar growth. Moore's law provides an important lens for understanding the environmental implications of IT.

This doubling pattern in most components of IT products has meant that devices have gotten progressively smaller, and by extension use less energy. Small devices cannot consume as much energy as their larger counterparts because there would be too much heat produced, and battery life would be intolerably short. Engineers therefore design products that consume use less energy. However, the amount of energy and water used in the manufacturing process has increased relative to the size of the product. For example, producing a two-gram microchip requires 500 times the weight of the chip in fossil fuel; in contrast, a 1000 kg automobile requires twice its weight in fossil fuel (MacLean and Lave 1998). This speaks to two phenomena that must be considered when understanding the environmental impacts of IT: scale effects and rebound effects. The scale effect is where "the environmental impacts due to the increase in the scale of economic activity can outstrip the positive impacts from any potential efficiency gains, " while the rebound effect is where "energy efficiency gains are more than offset by increases in use – thus the energy use 'rebounds' above the original level." (Matthews and Matthews, 2003, page 13).

Moore's law also allows IT products to be made quickly obsolete. So-called obsolescence cycles are an important trend in the environmental implications of electronic devices. Forced obsolescence can happen as IT products age – their computing power is no longer sufficient to handle current demands of consumer applications, and upgrading the product is not an option because the necessary components are no longer manufactured, or an upgrade would be uneconomical. Planned obsolescence is less straightforward, but involves IT companies deliberately designing products to function for a limited period of time. Because consumers are accustomed to replacing their products with regularity (a trend that has yet to abate, and seems to be increasing with small electronic devices like the cell phone), their expectations for durability may be limited.

The growth of smaller IT products as means of consuming E-Media is important. This miniaturization of electronic products has benefits (less overall raw materials consumed per product, less energy consumed during the operation of the device) but it presents challenges. These smaller devices have less valuable materials per unit to be recycled. In the 1990s, desktop computers had gold brackets that connected the CPU to the motherboard. The presence of a significant quantity of gold provided an economic case for recycling these products. Today, gold brackets are not used, and indeed in smaller products the volume of valuable materials is so minute that the economic case for recycling is less straightforward. Instead, strong regulatory regimes are necessary to encourage the recycling of E-Waste (such as the Environmental Handling Fee[1] in British Columbia). As miniaturization continues, the IT sector will have to deal with two new realities: more and more of the environmental impact of a device will occur in manufacturing of the device; and devices will be increasingly difficult to recycle when they are obsolete.

The facilities, processes and products of the IT sector create devices and platforms that deliver much more than E-Media. Although a consumer's use of a device ultimately decides what percentage of the environmental burden should be associated with E-Media, it's clear that devices are used for much more than replicating what was once paper-based media. At the same time, there has recently

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[1] http://www.encorp.ca/cfm/index.cfm?It=925&Id=1&Se=40

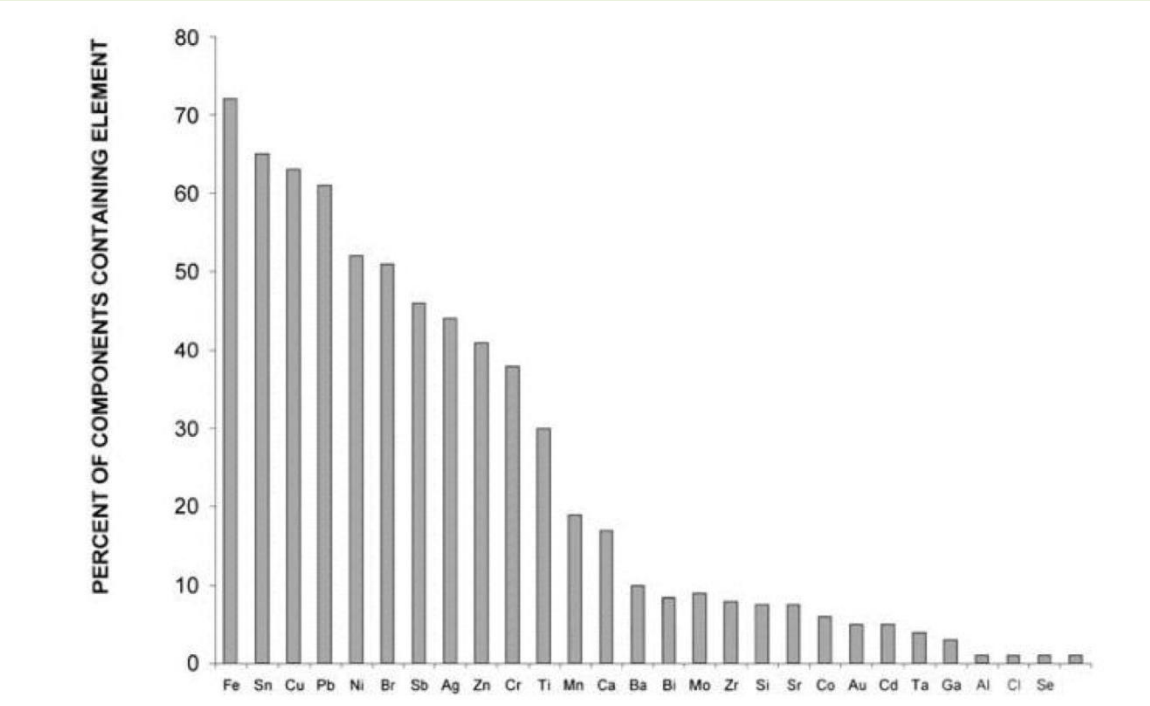
been an increase in devices that are dedicated to replicating the functions of paper-based media. During the Consumer Electronics Show 2010, a trade show held in Las Vegas each year, E-Readers were a popular new device (Messina, 2010). E-Ink, the technology that allows E-Readers to have impressive battery life (the Amazon Kindle can go a week on one charge[2]), cannot yet display web pages or video because it is incapable of frequently refreshing the screen. E-Readers therefore remain a single-function device, a relative rarity in the IT sector.

Any assessment of E-Media is a challenge. There are so many variables that demand consideration if the environmental burden of E-Media is to be understood. This wide dispersion of environmental impacts along a supply chain should not be ignored. Although E-Media may only account for a fraction of the impacts from hundreds of different factories and facilities, when considered in aggregate, the footprint is significant. This is particularly true for single-function devices, as the environmental impacts are not spread across a variety of uses.

6.1. Raw Materials

IT products of all types contain a massive variety of raw materials. Metals, chemicals and plastics are primary inputs, and hundreds are present, although often in a very small volume. Although the footprint of a particular IT product is small, as a whole “the sector is linked indirectly to virtually every subsector of the extractive and refining industries” (Graedel and Howard-Grenville, 2006, p.327). Figure 7 shows elements that are present in the components inside an electronic device.

[2] http://www.amazon.com/gp/product/B0015T963C/ref=sv_kinc_0



Source: (Graedel and Howard-Grenville, 2005)

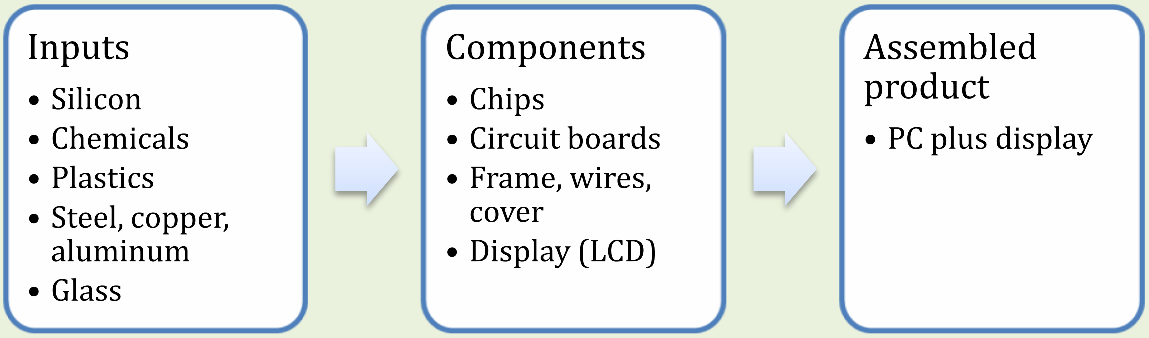
Figure 7: Elements used in modern electronics expressed as the percent of components containing a particular element.

To fully assess the environmental footprint of an IT product, the impacts of all the mining operations involved would be measured. This would be virtually impossible given the small quantity but vast variety of elements found in any electronic device. The number of elements present makes tracking down specific sources a challenge, allowing for disparities between different material sources. Some mines may abide by higher environmental standards than others. Further, some metals may be simple to extract, requiring minimal processing in order to achieve desired levels of purity. Other materials might require extensive inputs of energy and water in order to produce the desired purity, resulting in significant waste.

Raw material acquisition is therefore a concern for the IT sector, and by extension, E-Media. It depends on the depletion of scare resources, where extraction and processing can have negative impacts. Considering the impacts of digital media must therefore start with efforts to measure the energy and water requirements of extraction. . In simple terms, digital media is connected to the global mining sector, a connection that is not obvious, but important.

6.2. Materials Processing

IT products require much more than simple inputs from raw materials. Most of these raw materials are refined and processed to create highly specialized inputs for electronic devices. Given the wide variety of devices it is difficult to speak in general terms about the processes employed. However, all electronic devices do share similar functional components, and by understanding the processes that produce those components, we can better understand devices more broadly. A simplified model of the components inside an electronic device is shown in Figure 8. These components are common to almost all devices, from desktops to laptops to smartphones. Although the size and nature of each component will vary depending on the device, the processes employed to produce the components are similar. Figure 8 will structure our discussion of both the Materials Processing (section 6.3) and Manufacturing and Assembly (section 6.4)



Adapted from Williams, 2003.

Figure 8: Simplified Production Network for Computers

Understanding the material processing necessary to produce microchips is illustrative of the requirements of the IT sector at large. Van Zant, 2003, describes the technique of producing microchips (also known referred to as chips or semiconductor devices), a three-step process in order to be manufactured. This three step process of layering, doping/oxidization and patterning requires several chemicals in order to etch patterns in a silicon wafer and create transistors as a microscopic level. Table 1 summarizes the material and energy used in manufacturing microchips.

Table 1: Materials and energy uses in manufacturing microchips

Material	Description	Amount per memory chip	Annual use by industry worldwide (weights in metric)	Amount used to make chips in one computer
Silicon wafer		0.25 grams	4,400 tons	0.025 kg
Chemicals	Dopants	0.016 grams	280 tons	0.0002 kg
	Photolithography	22 grams	390,000 tons	2.2 kg
	Etchants	0.37 grams	6,600 tons	0.037 kg
	Acids/bases	50 grams	890,000 tons	4.9 kg
	Total chemicals	72 grams	1.3 million tons	7.1 kg
Elemental gases	N_2, 0_2, H_2, He, Ar	700 grams	12 million tons	69 kg
Energy	Electricity	2.9 kWh	52 billion kWh	281 kWh
	Direct Fossil Fuels	1.6 MJ	28 billion MJ	155 MJ
	Embodied fossil fuel	970 grams	17 million tons	94 kg
Water		32 liters	570 billion liters	310 liters

Reproduced from Williams, 2003

Given the ubiquity of microchips, Table 1 is representative of the materials and energy inside almost all electronic devices. The presence of these materials can be hazardous to the environment as well as human health, particularly if they are not managed appropriately. The semiconductor industry is becoming increasingly globalized, with more and more of the production being under the control of subsidiaries of multinationals or local firms in East Asia (particularly Taiwan and China). These companies, which are less exposed to the regulatory scrutiny of the developed world, provide almost no environmental information about their production processes (Williams, 2003).

6.3. Manufacturing and Assembly

The manufacture of an IT device requires the integration of four components (chips, circuit boards, frames/wires/covers, display). While we have already discussed the materials and energy requirements for the production of chips, we will briefly cover the impacts of other components. Our focus will be on the environmental impact of the integrated product.

Williams, 2003, summarizes the environmental impacts of the circuit board, a familiar green rectangle so commonly associated with electronics. Composed of layers of insulating and conducting materials, the main environmental hazards associated with circuit board production are from the chemicals and water used in production. Each layer in the board must be etched, made conducive or insulated through various chemical processes. This includes etching copper with acids or alkaloids, removing photoresist materials with hot potassium hydroxide, and soldering layers together with tin-iron solder.

The liquid crystal display (LCD) screen is the most commonly used today in electronic devices. Although variations exist (for example, LEDs are LCDs but with light emitting diodes instead of cold cathode fluorescent lamps for backlighting), LCDs can be found in almost all electronic devices, with the exception of E-Readers, which employ E-Ink. Table 2 summarizes the environmental impacts of a 15" LCD. The data is illustrative of the embodied environmental impacts in LCD monitors, although precise levels would vary with monitor size.

Table 2: Chemicals, Energy and Water Use in LCD Manufacturing

Material/input	**Amount used per monitor**
Photolithographic and other chemicals	3.7 kg
Elemental gases (N_2, 0_2, argon)	5.9 kg
Electricity	87 kWh
Direct fossil fuels	198 kg
Embodied fossil fuels	226 kg
Water	1,290 liters

Source: Socolof et al. (2002)

The chips, circuit boards and display of an electronic device are connected together using various bulk materials. Plastics are perhaps the most common, and a wide variety is found inside each product. Because plastics are chosen for both their material properties (strength, weight, flexibility) as well as aesthetic value, often times products will contain 7 or more different type of plastics (Shimoda et al, 1998). This variety makes the recycling particularly challenging, and is further compounded by trends towards miniaturization of products.

The total environmental impacts of a one desktop computer can be found in Table 3. While this data is for a desktop from the late 1990s, and includes a CRT monitor, it nonetheless speaks to how the environmental burdens of electronic devices can be embodied inside the product itself. Each electronic device might have a different set of burdens, and this data set should be considered illustrative. The challenge of data availability is acute when measuring the footprint of the IT sector. As stated by Williams et al, 2004, "understanding … the environmental implications of information technology is still in its infancy." Much of the data has to be produced at the sector or facility level, using input-output analyses. IT firms are often reluctant to release specific inventory analyses because they may indirectly reveal information about technical processes being employed in production. Researchers are therefore forced to adopt crude measures of environmental footprints (Williams et al. 2004).

Table 3: Fossil fuels, chemicals and water consumers in the production of one desktop computer

Item	Fossil fuels (kg)	Chemicals (kg)	Water (kg)
Semiconductors	94	7.1	310
Printed circuit boards	14	14	780
CRT picture tube	9.5	0.49	450
Bulk materials – control unit	21	NI	NI
Bulk materials – CRT	22	NI	NI
Electronic materials/chemicals (excluding wafers)	64	NI	NI
Silicon wafers	17	NI	NI
Total	**240**	**22**	**1,500**

Source: Williams, 2003
Note: NI = not included in analysis

6.4. Distribution and Consumption

The distribution networks of electronic products, in essence the platforms for consuming E-Media, are truly global. With raw materials sourced from virtually every mine and highly specialized factories worldwide contributing components, final products are generally assembled in East Asia (Taiwan, China, South Korea) and shipped across the world. However, because the weight of the products is so small the contribution of shipping to the total footprint is negligible. The retail outlets that distribute electronic devices are also part of this distribution network, but since they sell such a wide variety of products it is difficult to connect the footprint of these facilities to E-Media.

As has already been discussed, the amount of energy consumed by digital devices is decreasing on a per-unit basis. The IT industry has a vested interest in making smaller and more energy efficient products, as it satisfies consumer demand. There is the benefit, however, that these smaller devices consume less energy during their lifespan. For example, a LCA of a Nokia 3G wireless device suggested that only 30% of the products total energy use occurred during the consumption stage (McLaren and Piukkula, 2004). 3G devices similar to the one studied may play an increasingly important role in the consumption of E-Media. Recent information released by Apple Computer suggests on their corporate website that, on average, 53% of life-cycle greenhouse gas emissions occur during the product use stage (Apple, 2010). However, there are no detailed breakdowns on the assumptions of their LCA, particularly assumptions on the energy use associated with manufacturing the product.

There are other variables in the consumption stage that need to be considered from the perspective of E-Media. E-Media's share of the environmental burden of a device is influenced by how the device is used. For example, a computer with a single user that uses the device exclusively for reading the news translates into a high environmental burden for E-Media. A computer with multiple users who use the device for a wide variety of purposes results in a more dispersed environmental burden. The useful life of the product can also be of great influence. Devices that last a long time distribute their footprint over a longer time scale, ensuring that the energy, water and materials invested in the device are given credence through an extended useful life. Devices with short lifespans, in contrast, only intensify the burden of the device. These variables highlight the problematic trend of obsolescence in IT devices, and also show how consumer behaviour can influence the environmental footprint of E-Media.

Another area of environment impacts in the consumption phase is in the data centers that host E-Media. In 2006, data centers in the United States consumed 1.5% of the total electricity bundle in the United States (EPA, 2007). This figure doesn't include all of the embodied energy inside the servers that make up a data center, and given the footprint of other electronic products, the impacts of servers is likely large. The percentage of total data center energy consumption that can be attributed to E-Media is difficult to ascertain as data that breaks down information consumption across the United States is available only at a granular level (Bohn and Short, 2009).

The obsolescence patterns of IT that shorten the consumption stage of electronic devices may, however, change. The recent success of the Apple App Store[3], and Google Android Market[4] are indicative of more innovation migrating towards services rather than hardware. If the 'latest and greatest' is simply an application, rather than a new device altogether, the marketplace might respond by spending more on new software rather than new hardware. While this trend is by no means certain it does show that the IT sector has the potential to extend the obsolescence cycles of hardware and focus more on software. However, the same company that championed the App Store just released a new product, the iPad, that is attempting to create an entirely new niche of hardware. Evidently and unsurprisingly, the IT sector still prefers the profits of hardware sales to the more environmentally benign software and services model.

[3] http://www.apple.com/iphone/iphone-3gs/app-store.html
[4] http://www.android.com/market/

6.5. End of Life

End of life (EOL) management for electronic products is a challenge for the IT sector. There are three key issues that influence EOL: first, the variety of inputs into an electronic device, as well as continued miniaturization, make it difficult to recycle and retain valuable elements inside the device; second, E-waste is processed predominantly in developing countries (China alone processes 70% of E-Waste (Stone, 2009)); and finally, the volumes of E-Waste generated is a significant concern as consumer's purchase more and more devices, and as Moore's law continues to render older devices obsolete.

In the United States, 15 lbs of E-Waste was generated per capita in 2007, of which only 2.7lbs was recycled. The rest was disposed of, with most going overseas; for example, in 2005 80% of CRT monitors were shipped outside of the United States for EOL management (all figures EPA, 2008). Given that consumers are anticipating more electronic devices in their lives, and the continuation of rapid obsolescence of IT products, the volume of E-Waste generated can be safely projected to increase. This disposal of E-Waste overseas is a source of potentially hazardous and toxic materials, as developing countries lack the regulatory regimes and strength of governance to ensure compliance with best practices for E-Waste handling (Stone, 2009). The human hazard associated with E-Waste is an acute challenge for the IT sector, and for E-Media as well. Workers are often exposed to very high level of carcinogenic, mutagenic or otherwise harmful elements. If more and more content is consumed with electronic devices, the volume of E-Waste generated will likely increase. Without the necessary regulations, which research shows are costly and require additional payouts from both consumers and producers (Macauley et al, 2003), the challenge of E-Waste will continue to grow. Although E-Media is only one function of electronic devices, it is nonetheless an important one, and the commensurate connection with E-Waste is worthy of consideration.

Moore's law also is making the challenge of E-Waste more complex. Smaller devices have the benefit of having fewer materials to be disposed of. LCD displays replacing

CRT displays, for example, reduces the overall volume of waste being processed and avoids the necessary treatment of lead in a CRT's glass panel. However, smaller devices have, by their very nature, less materials inside, and are therefore less economically attractive to recycle. Further, Moore's law implies that a steady and increasing flow of E-Waste will generated. Given that these devices have significant sums of embodied energy, materials and water, recovering these inputs in the EOL management stage and retaining as much embodied value as possible would be an ideal approach. However, the constant progress of technology and the highly specific requirements for the components and materials that comprise new devices make this level of recovery unlikely.

7. The Forestry Sector and Media

Anything on paper is connected to the forests, pulp and paper mills, and printers of the world. Paper media is easier to understand than E-Media. Why? First, the number of paper product functions is small in comparison to an electronic device. Second, the supply chain that produces paper media is well understood and has fewer actors than an IT equivalent. Third, paper media is relatively stable and has not changed dramatically in the last century; electronic devices change rapidly. Given the simplicity, knowledge and stability of paper, it is relatively easy to connect the environmental burden of forestry with paper media than the environmental burden of IT with E-media.

There are certain characteristics of the forestry supply chain that produce unique products. Forestry is a remarkably diverse industry: raw materials can be harvested from forests the world round, sometimes responsibly and sometimes not. Pulp and paper mills can be new and state-of-the-art, or they can be out-of-date and have fewer environmental controls in place. Paper media itself can be something temporary, like a newspaper, or something enduring, like a book. In short, at each stage in the life cycle of paper media, there are many attributes to consider in assessing environmental performance.

Forestry is also connected to many subsectors that aren't paper. For example, the harvesting of trees provides the inputs for dimensional lumber, panels, engineered wood products, and increasingly, energy from biomass. Given this complexity of outputs, every forestry operation may have unique industrial structures combined with unique raw material inputs to cater to different market segment.

Our review of forestry is briefer than our exploration of the IT sector, since E-Media is the emergent trend which is more complex, is lacking in some basic knowledge on environmental impacts and has a relatively short history. We will confine our comments to highlighting the indicators at each stage in the life cycle of paper media that demonstrate the strength/weaknesses for forestry to produce a highly sustainable product.

7.1. Raw Material Extraction

An unavoidable truth is that the raw material extraction from forests requires the felling of trees. While tree harvesting is theoretically sustainable, as the resource can regenerate itself over time, proper management is necessary to ensure the sustainability of the harvest. Harvesting can deplete biodiversity and compromise ecosystem resilience. There can also be adverse social impacts, as indigenous groups and local communities are not necessarily included in the management of forested areas.

The 'sustainability' of a forest operation is very site dependent and subject to various jurisdictional regulations (Indufor Oy 2010). The knowledge and capacity of the company engaged in harvesting is also important. Harvesting operations can take place in an intensively managed plantation, or in a natural forest (either primary or secondary growth). Harvesting also occurs in the tropical forests of the global south, or the temperate forests of the global north. Each type of operation has its own unique challenges. Plantations can ensure that the disturbance of natural forest is minimized; however, they can also be a drain on local water resources. Harvesting in tropical forests is a particular challenge – the high levels of biodiversity and fragile ecosystems can lead to destructive forest operations. In temperate and boreal forests, harvesting can attempt to emulate natural disturbance.

Forestry has responded to challenges in harvesting by developing and adopting third party certification schemes. These standards are defined and approved by organizations such as the Canadian Standards Association, Forest Stewardship Council, Programme for the Endorsement of Forest Certification and the Sustainable Forestry Initiative, are helping the marketplace better understand the impacts of harvesting operations. The certification schemes require auditing by third parties to ensure that sustainable forest management is practiced. Although the standards vary, they all focus on the ecological health of the forested area, and some even set standards for social/cultural sustainability. In the 1990s, all of these standards were developed in response to continued pressure from civil society and governments for forest operations to become more accountable, especially where the regulatory environment was weak. By-and-large the adoption of certification schemes has been of benefit to the industry in improving its reporting, monitoring and verification systems for supply chains.

7.2. Material Processing

Wood chips are the primary raw material input in the manufacture of paper. These chips are a byproduct of other forestry operations, or in some instances, logs may be converted directly to chips. These chips, along with recycled fibre, are integral raw material inputs in the production of most papers.

Wood is cellulose held together with lignin, a compound that can comprise up to 25% of wood's weight (Graedel and Howard Grenville, 2005). To create pulp, the lignin is brightened or removed from the wood using either mechanical or kraft processes. The kraft process is the more common method of delignification, and involves cooking small chips of wood under high pressure and high temperature, with a mixture of chemicals. Following this process, the pulp is washed extensively, using a significant amount of water. Pulp that is destined to become whitened paper will go through a bleaching process.

The actual paper making process involves dropping pulp, which at this stage is about 1% fiber and 99% water, onto a wire screen moving at high speeds. As the pulp moves along the screen, water is eliminated first by falling through the screen, then by pressing, and then by applying heat. The final product is a cylinder of paper ready for delivery.

There are three key environmental issues associated with papermaking. First, energy use can be substantial, and historically the pulp and paper industry has been a large energy consumer. New technology has now been adopted to use biomass as a source of energy with some mills claiming to produce paper with almost zero net carbon emissions[5]. As more and more mills utilize their waste stream as a source of energy, the overall environmental burden of paper media will decrease.

Second, water use is a key concern in papermaking. Older mills can use as much as 50 to 80 m^3 of water per ton of paper. Newer mills, however, are able to use only 5 to 8 m^3 per ton, a ten-fold increase in productivity enabled by closed-loop water recovery systems (Graedel and Howard-Grenville, 2005). In areas of relative water abundance, using more water in papermaking is not necessarily a bad thing if wastewater is properly treated.

Third, and finally, papermaking revolves around the chemicals necessary to bleach paper. Chlorine used to be the dominant form of bleaching, and had as a byproduct the hazardous chemical dioxin. However, modern mills no longer use chlorine, and instead use ozone, chlorine dioxide or hydrogen peroxide to bleach paper. All of these options avoid producing dioxin.

7.3. Manufacturing and Assembly

For the purposes of this analysis, we consider the printing process to be the “manufacturing and assembly’” stage of paper media. Printing is the method of transferring, photographically or electronically, an image onto a plate, where the

[5] http://www.catalystpaper.com/sites/default/files/factsheet-cooled-2007-11-27.pdf

areas to be printed are raised higher than the rest of the plate. The energy use of the printing process is very small in comparison to other stages in the life cycle of paper media, and should not be considered a significant concern.

The chemical uses in printing are primarily found in the inks. These printing inks can toxic, as well as, the organic solvents used for periodic cleaning of printing plates. Either of these processes could release Volatile Organic Compounds (VOC) into the atmosphere. Recently, the print industry has made significant strides to avoid the use of VOC solvents (McCourt, 1999).

7.4. Distribution and Consumption

The distribution networks that deliver paper media are a significant environmental burden. Unlike E-Media, the delivery of a newspaper, book, or magazine on paper requires trucks, roads and the consumption of fossil fuel. For E-Media, in contrast, the user can connect to the Internet and download a copy of the relevant file. The distribution footprint of certain products, particularly daily newspapers and magazines, is of particular concern. Because these paper media products do not last very long, the environmental burden associated with their distribution is not spread over a longer period of time, therefore any negative implications are intensified.

At the same time, consumer behaviour and purchasing habits can significantly mitigate the environmental burden of this stage of the paper media cycle. Some products, such as books, once delivered, can last a long time. The book can be shared, either between friends or through a library, and the more individuals who read this book the more dispersed the environmental burden becomes. The same can be said for printed newspapers and magazines. If many people read the same edition of the paper media product, the burden is dispersed. However, there are occasions where the distribution and consumption of paper media can be rather inefficient. A rural home with a single occupant that has a newspaper delivered daily has transport burden that makes delivering paper media problematic.

There are scenarios where paper might make sense, and there are scenarios where competing with an E-Media on an environmental basis might be futile. In the end, it's important to understand the sensitivity of the assumptions made in any analysis of the distribution and consumption of paper media.

7.5. End of Life

Paper media, unlike E-Media, can be both easy and economical to recycle. In 2009, 64.3% of paper consumed in the United States was recovered for recycling[6]. Paper products that come from post-consumer waste (either 100% or a fraction thereof) are popular in the marketplace. Recycled fiber can be mixed with virgin fiber to produce new paper, or be used as insulation in homes, known as paperwool insulation (Schmidt et al, 2004). Paper can also be incinerated, not an ideal option, although it does have the potential to offset the use of fossil fuels and therefore reduce carbon emissions.

The key issues for paper EOL management revolve around assurance of recovery. When paper ends up in a landfill, it decomposes and generates methane (Pingoud and Wagner, 2006). The landfill paper then contributes to the overall environmental burden of paper media by creating more greenhouse gas emissions than might otherwise exist. In contrast, if paper is recovered, there are a number of useful methods of preserving the value already embodied in the paper, as well offsetting the flow of virgin fiber and fossil fuel extraction. In short, paper is a valuable waste stream. Industry and consumer habits have evolved to recognize this value, and the habits and infrastructure necessary are both in place.

8. Discussion

As we reviewed IT and forestry we identified the indicators from each sector that are important to understanding the environmental burden of media. The next step is to consider these variables in light of the framework we developed in Section 5.

[6] http://paperrecycles.org/news/press_releases/2009_recovery_stats_released.html

These benchmarks were developed to assess the IT and Forestry industrial systems on a long time scale.

8.1. The Potential of IT

Perhaps the greatest challenge for IT, thus E-Media, is in controlling the output of E-Waste. While Moore's law allows for remarkable technological progress, with more devices available for less money, there is a downside. This progress necessitates a cycle of obsolescence, which implies a steady flow of waste. Because the processes necessary to produce electronic devices require extremely pure inputs, using E-Waste as a source of inputs for new electronic devices remains an elusive goal. Therefore, the IT sector is structurally ill suited to attain a closed material loop. The pace of innovation, the miniaturization of devices, and the variety of materials inside any device make mining the waste stream of IT for new IT products almost impossible.

Compounding this challenge, we are only beginning to understand the scale and scope of E-Waste. Moore's law has also lead to the price of electronic devices decreasing. More and more consumers around the world can afford computers, cell phones, and perhaps soon, tablet computers or E-Readers, and all of this new consumption will create larger and larger waste stream. All of these trends make IT's ability to close the loop, minimize waste and recover outputs unlikely.

Our second benchmark is whether an industry is capable of preserving the value added inside a product, while working to reuse components with significant embodied environmental impacts. As was shown, the production of electronic products requires a considerable input of energy, water and raw materials. These inputs are embodied in the product, but the difficulty of processing E-Waste means that many of these embodied inputs are not recovered in an equally useful way. This is an excellent example of downcycling, where something valuable is only capable of being reused in much more crude application.

There are, admittedly, few truly renewable resources. And for the IT sector, which requires a vast array of metals and chemicals to achieve its technical wonders, the use of renewable materials has been limited to soy-based plastics for cell phone cases (and other similar applications). Given that the IT sector and the devices it produces have so many positive environmental impacts (for example, the forest products industry credits IT as being central to its environmental management efforts (Armstrong et al, 1998)), it would be unfair to judge IT harshly for its dependence on non-renewable materials. The industry has proven remarkably innovative at using new metals and chemicals, so as some elements become increasingly scarce, the sector can be expected to engineer the necessary work-around. However, the IT sector currently could perform much better at understanding the origins of the raw materials employed. Because so may hundreds of suppliers are involved, both in producing components and supplying raw materials, it's exceedingly difficult to trace the supply chain of an electronic product. The sector is likely to come under increasing pressure to have a more transparent and accountable supply chain. In the United States, for example, there is legislation currently being considered that would force IT to identify any potential conflict minerals present in a product and ensure that these are not imported to the United States.[7]

The greatest strength of IT, and related to our fourth benchmark, is the functional redundancy of the devices it produces. One electronic product can perform a vast array of tasks, spreading the environmental burden of its manufacture and disposal amongst all of these activities. E-Media consumption is just one aspect of what an electronic device can do, something that should be considered closely when trying to gauge the environmental implications of the paper to pixel transition. The number of functions a device provides, in addition to the lifespan of that device, could lead to E-Media being the more environmentally benign media consumption option. However, this is only a possibility, not necessarily a certainty.

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[7] http://www.opencongress.org/bill/111-h4128/show

IT does fail, however, at creating facilities that are functionally redundant. Again, Moore's law and it's implied pace of innovation puts a shorter lifespan on the factories that produce the semiconductors, displays and other components in an IT device. As new technical processes are developed, plants can be rendered obsolete. The obsolescence of facilities does not occur at the same pace as the devices they produce, but it does imply that the environmental burden's associated with facility construction are concentrated over a shorter period of time. For example, an Intel plant in Ireland was shut down in 14 years after opening, because it was only capable of producing older products for which there was no longer demand[8].

8.2. The Potential of Forestry

Forestry has made strides in closing its material loop. At the material extraction stage, forest operations actively replant after harvesting, and recently, have been replanting a diversity of species to better manage the biodiversity of the land base. At the materials processing stage, pulp and paper mills are shifting towards recovering their wastewater, as well as using waste to produce energy, with the eventual goal of becoming energy self-sufficient. EOL management in forestry is also improving; the recent recovery rate of 64.3% for 2009 in the United Sates is a record. The consumer is accustomed to paper recovery programs, and the economic case is supported by the strong demand for paper that contains post-consumer waste.

Paper media will struggle to close its material loop given its dependence on the transportation sector to deliver media. Products like newspapers, with a heavy transport burden, are exposed to the environmental impacts of the vehicles and fuel necessary for delivery. The methane emissions from unrecovered paper media is also a source of concern. Any efforts to encourage higher rates of recovery will lighten the environmental burden of paper media. It should also be noted that this potential to achieve a closed material loop is just that: a potential. Not every

[8] http://www.irishtimes.com/newspaper/frontpage/2009/0722/1224251066354.html

scenario in paper media is going to have an entire supply chain that is sustainably managing its forest, investing in technology to recover wastewater and be energy self sufficient, or ensure that printing process avoids any harmful chemicals. However, the best-case scenario inside forestry already represents a strong example of a type II industrial ecology.

The inherent recyclability of paper media ensures that the value added to the product, as well as the embodied environmental impacts, are preserved to some extent. Although post-consumer paper waste cannot be reused in perpetuity, it can be blended with virgin fiber. In short, the waste of paper media is a useful and valuable input for additional paper media. Pressure from environmental groups, as well as consumer awareness, has resulted in more post-consumer waste being used in paper media. In a best case scenario paper media can move towards a type II industrial ecology based on it’s ability to reuse it’s waste stream, and preserve the embodied value and impacts of a product.

The renewability of forest products is the paper media’s greatest asset. When done properly, forest operations can minimize environmental harm, preserve biodiversity, and produce a product that is fully renewable. However, there is a level of oversight from both governments and third party certifiers that is required. And it cannot be assumed that this oversight exists for all of the paper media in the marketplace. It is significant that the structures for certification do exist, which speaks to forestry’s potential from the perspective of industrial ecology. The paper and printing segments of the paper media supply chain have also demonstrated an ability to avoid the more hazardous and harmful chemicals used in the papermaking and printing processes. Nonrenewable materials are still necessary at some stages but the more modern facilities are able to recover and reuse a high percentage of these nonrenewable inputs.

The functional redundancy of paper media is less clear. The content of much paper media, particularly newspapers and magazines, age very quickly. The product is therefore useful primarily as an input for recycled paper. However, the facilities that produce paper media do have a high degree of functional redundancy. A pulp mill, for example, can double as a power plant if there is fiber available for the biogasification process. It could also potentially operate as a bio-refinery, producing bio-chemicals and other bio-products (FPAC, 2010). Furthermore, pulp and paper mills could last for decades, especially if hidden subsidies are available, and given their diversity of functions, the environmental burden of facility construction is spread over a wide variety of products and a long time scale.

9. Conclusions

After gauging the potential of IT and Forestry against our benchmarks of industrial ecology, we can illustrate how each sector can improve the environmental performance of the media it delivers. It's clear that the best case scenario in each industry is dependent on several things: a transparent and measured supply chain; research and development of new technologies to avoid hazardous materials and waste streams; a robust end-of-life management strategy that recovers the value embodied in a product and avoids releasing hazardous waste into the biosphere; and a sincere effort to identify and mitigate the variables that have most influenced the environmental burden of a media product.

The marketplace for media consumption is clearly changing. Our survey shows that consumers expect to use electronic products to get more of their media as time passes. However, this transition is not inevitable, linear or clear-cut. The marketplace is still willing to pay for paper media, finds paper media sources more credible, and paper based advertising to be more effective. The paper to pixel transition will include a shift towards digital media, but also a shift from certain types of paper media (e.g. national newspapers) to others (e.g. local newspapers).

The complexity of the transition is a challenge for traditional measurements of environmental impacts, such as LCA. The diversity in function, lifespan, geographical space and time horizons, allows for massive variance between one scenario and another. The field of industrial ecology contains important concepts and ideas that can help shape a more holistic understanding of what it is to be "green". Our benchmarks are principles against which the paper media and digital media can be compared. Rather than definitively answering the question of "which is better?", we suggest a framework that can lead to better questions and analysis. Considering the potential of each industry, IT and forestry, to achieve a type II industrial ecology is facilitated by these benchmarks. And our analysis suggests that best-case scenarios in forestry today are strong type II ecologies. IT, on the other hand, is a rapidly changing and relatively new industry. At best, IT scenarios are a weak type II but more likely a type I. The rapid obsolescence of IT products, the unrelenting innovation of new products and the commensurate flow of E-waste, and the complex and sometimes opaque supply chains in the IT sector indicate that the sector has significant challenges ahead in achieving type II characteristics.

The transition from paper to pixels is not an either/or situation. In both sectors, there are scenarios where the environmental burden is tolerable, or even preferable to alternatives. Understanding these scenarios, however, requires an analysis of the sector that delivers the media content. It is not sufficient to simply understand the energy consumption of an electronic device running for three years; the energy (and other impacts) embodied in the device are equally, if not more, important. It is also not sufficient to judge the burden of paper media simply by the transport networks required to get the product to a consumer. The sustainability of the forest operation, the technology employed in the papermaking and print processes, as well the utility of recovered paper are all key considerations. The environmental impacts of this industrial transition therefore lie in the potential of each industry to reduce its environmental burden to the greatest extent possible.

Annex 1: IT Information

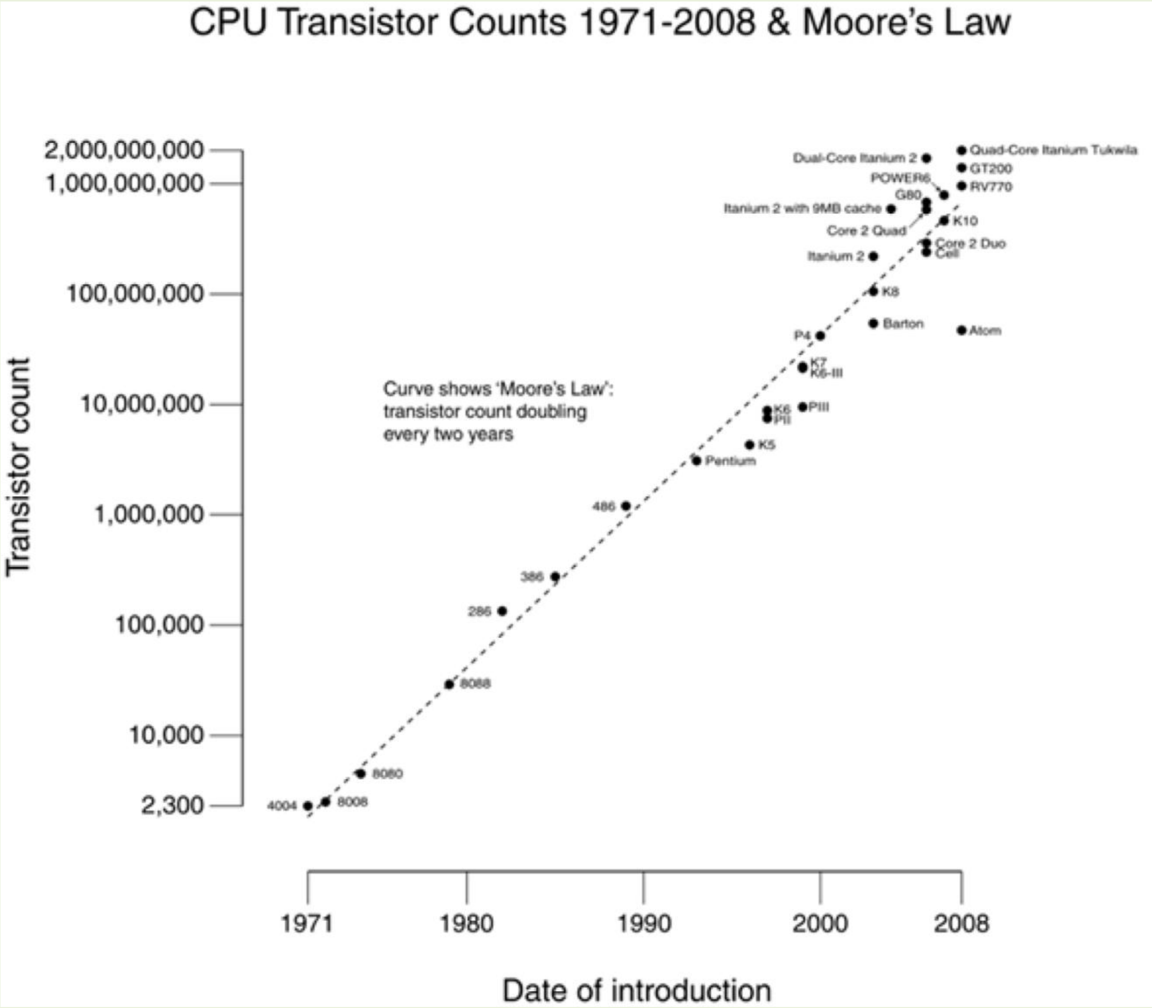

Figure 9: Moore's Law.

Source: Wikipedia (http://en.wikipedia.org/wiki/Moore's_law)

Annex 2: Detailed Summary of Survey Results

We conducted a survey of over 1400 consumers in North America, half in Canada and half in the United States. We made sure that our responses matched the latest census results for age and gender. On average, the respondents had 2.1 computers per household, 1.8 mobile phones per household and had been using the internet for 4.8 years. Below we present key findings from the survey.

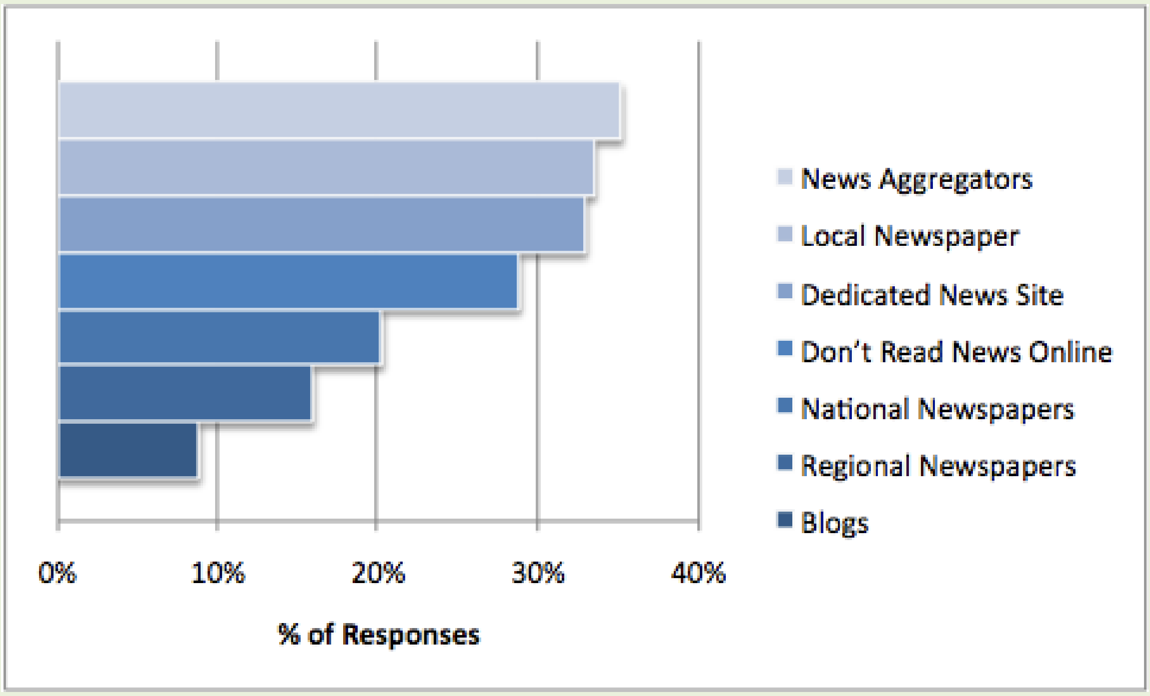

Figure 10: Online News Sources

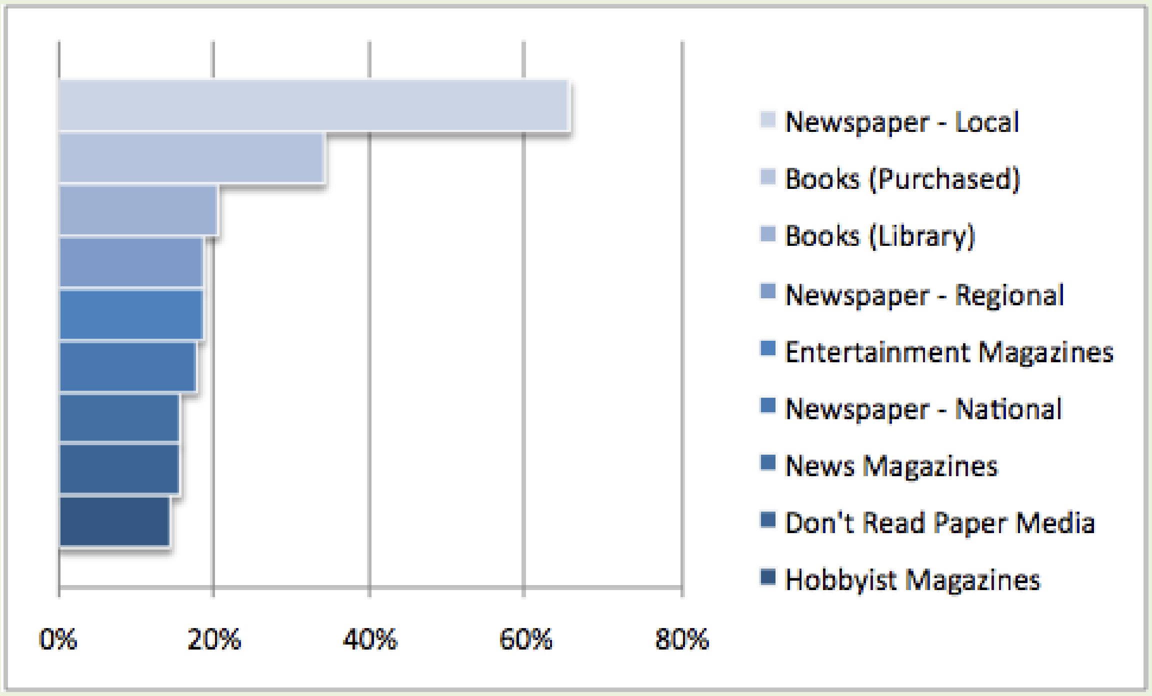

Figure 11: Paper Media Consumption

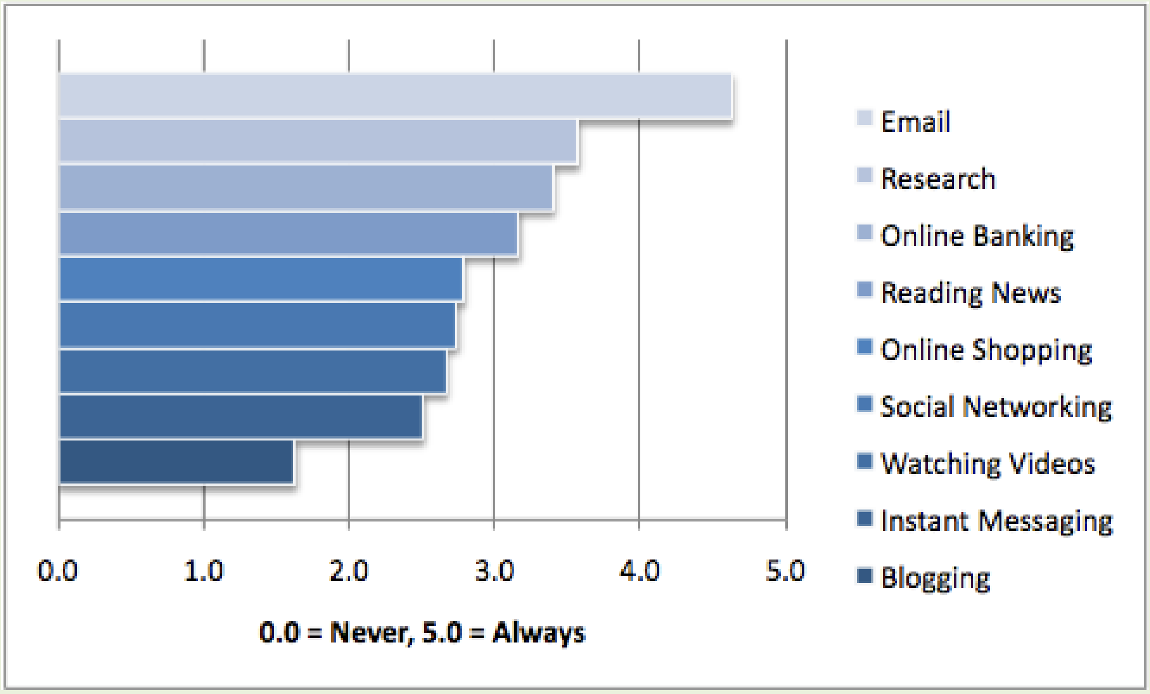

Figure 12: Use of Online Services

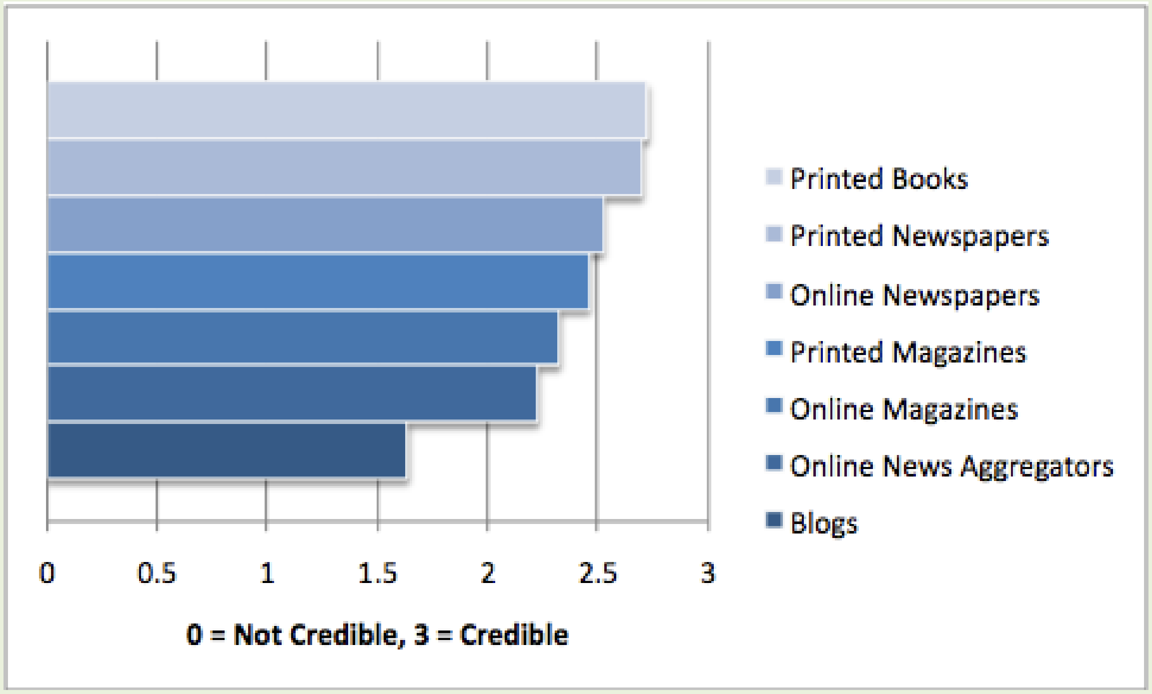

Figure 13: Credibility of Sources

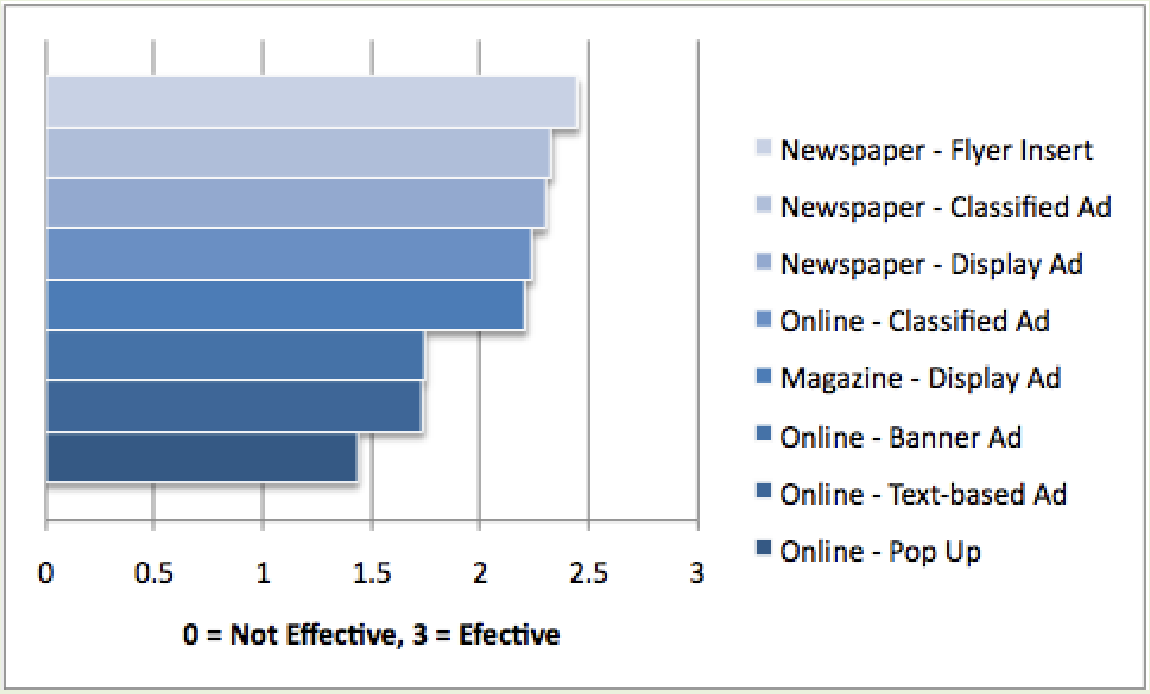

Figure 14: Effectiveness of Sources

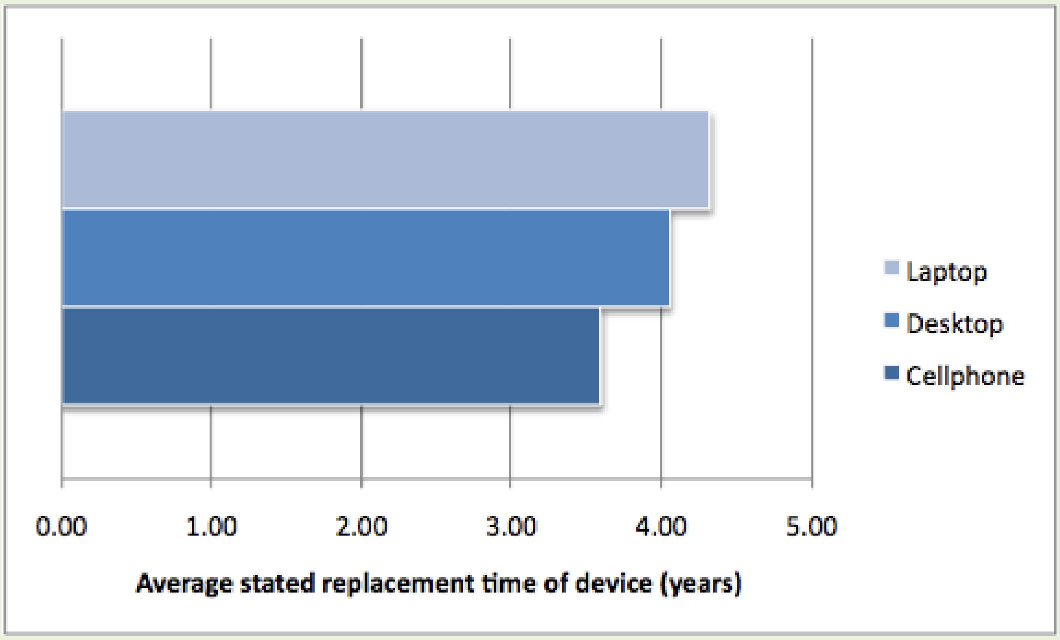

Figure 15: Frequency of Replacement

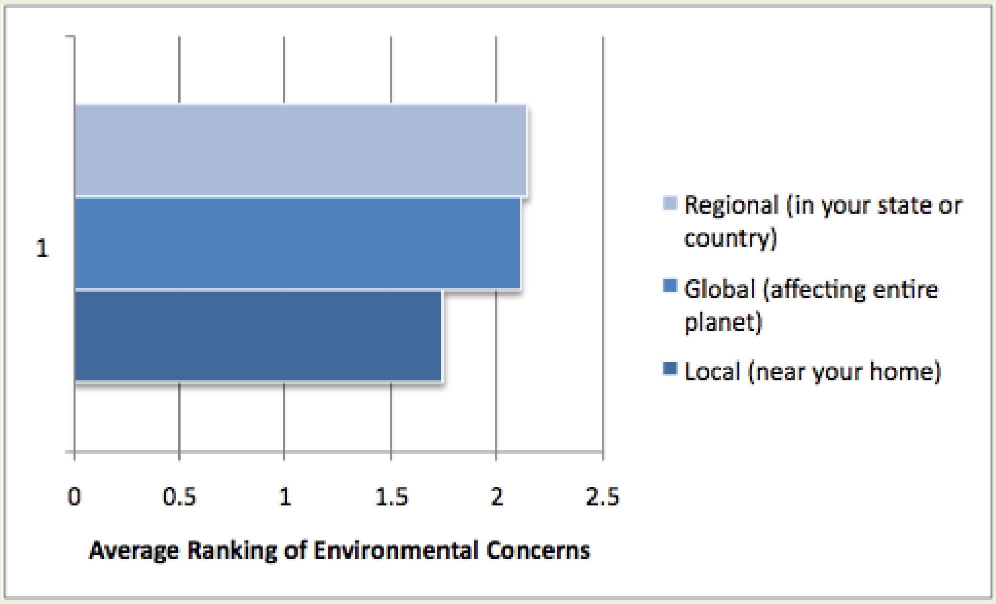

Figure 16: Ranking of Environmental Concern by Global, Regional or Local Priority

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