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Reducing the Greenhouse Gas Emissions of Commercial Print with Digital Technologies

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***Abstract*— Many commercial print applications - book publishing, newspaper and magazine production, paper-based marketing material and numerous others - are characterized by high levels of over-production and waste. Printed matter is manufactured and distributed to end users, retailers and warehouses, where a proportion is unwanted or loses its value before being sold. Subsequently, obsolete printed material is recycled or discarded as waste. This occurs in large part as the result of business models built around traditional large scale offset litho, web-offset and gravure printing presses (we call these *analog* print technologies) which have evolved to deliver very low cost per page on large print runs. Newer *digital* press technology has the potential to re-engineer print business models and eliminate much of this waste. Paper is an exquisite technology that offers a durable, high contrast, high resolution and low power color display surface at very low cost. Despite this low cost and low environmental impact during use, paper has significant embedded Greenhouse Gas (GHG) emissions resulting from other phases of paper's life cycle. In fact, in most print applications, including those mentioned above, paper is the *dominant* contribution to GHG emissions. Although alternatives to paper such as e-books, e-paper and erasable ink have been proposed, it is not clear that these will succeed or that they will reduce emissions; it would certainly be unwise to rely on them as the sole route to abatements. This article quantifies the GHG emissions due to inefficiencies in current commercial and office print applications and describes improved business models built on digital print and distribution technologies to conserve paper and enable GHG reductions.**

***Index Terms*—Printing, Digital Press, Global Warming Potential, Abatements**

I. Problem Addressed

WASTE occurs in print applications for many reasons. A very significant cause in the single largest application by emission level – newspaper publication – is print overrun and returns: more newspapers are printed than will be sold to customers. Up to 20% are printed, distributed and then taken to recycling or landfill without being read [1]. Another cause of waste is the mechanical setup process, requiring significant test printing before actual production can commence. This setup process also has an economic impact: it means that the capital cost of a print run is significant. Large print runs are cheaper per item, and it is expensive to print more subsequently, therefore encouraging overproduction to avoid risk of stock-out. A less obvious, though potentially more significant, source of waste is the large portion of printed material that goes unread due to irrelevance to the customer or recipient. There can even be perverse incentives to over-production such as distributors who are paid per copy carried but feel no cost effects from delivering too many. Sometimes there are simple solutions: Office printers often default to simplex printing even if they are duplex capable. Undoubtedly some of the waste would be eliminated from traditional analog print workflows if the cost of the carbon was internalized. But we believe that the most significant opportunities will be realized by a shift to new business models based on the more flexible and responsive digital presses.

II. Knowledge of Prior Work

The Carbon Trust have looked at newspaper operations [2] and determined that paper is the dominant component of overall GHG emissions. However, their prescription for reductions is limited to optimal paper supply sourcing and does not analyze business model re-engineering. The Smart 2020 [3] report from The Climate Group and GeSI identifies GHG savings for paper of around 70 million metric tonnes CO_2 equivalent (MMT CO_2e) per year, compared to projected business-as-usual emissions for 2020, through the application of IT solutions. The report uses a valuable methodology, which has provided inspiration for our approach. However, the report does not consider the application of digital print technologies to reduce emissions associated with paper use. Instead, it focuses on reducing paper use through the deployment of e-paper (low-cost low-power electronic viewers which are slowly appearing)[1] and alternatives to paper workflows, such as electronic bank statements. This analysis is cursory relative to the more detailed analysis they provide of other opportunities, such as smart grids and energy efficient housing. In a novel approach Counsell and Allwood [4] examine the potential for reducing the GHG impact of office paper through actions such as incineration, localized production, use of annual fiber such as Kenaf, and erasable ink, but they do not consider business model re-design. This is where we believe the biggest potential lies and accordingly

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[1] Their analysis does not consider the embedded carbon and energy consumption which would potentially result from the proliferation of new e-reader devices. To an extent, this is also true of our analysis:, we do factor in a rough estimate of the embedded carbon and energy use of the printers necessary, but we do not consider how this will change as digital commercial printers are deployed. Evidence suggests that in our case, this is likely to be a significantly smaller factor: commercial printers with a high throughput of paper have emissions from power consumption and manufacture dwarfed by that of the paper used, and such printers will be displacing existing analog printers. More detailed analysis of these factors is a topic for further research.

our estimate for GHG reduction is much higher as we show below.

III. Project Undertaken

Our objective is to produce a more focused examination of the global carbon footprint of printing using the same methodology as The Climate Group – in other words, to model business-as-usual GHG emissions across all print applications for the year 2020, and then highlight the abatement potential enabled by digital technology.

IV. Modeling Approach

The following section provides details about how we estimated the overall carbon footprint of printing for the year 2020, along with the abatement potential enabled by digital efficiencies.

A. Global Warming Potential of Printing Paper

We based our model on the premise that paper, or more accurately, printed media, is the dominant source of GHG emissions for most print applications. To estimate the amount of printed media that will be consumed in 2020, we utilized proprietary third party projections of equivalent A4 pages printed for 2012, as well as a 2010-2012 compound annual growth rate (CAGR), by print application. These data apply to analog and digital printing for each print application. We applied both positive and negative CAGRs through 2020 to estimate printing volume for that year.

To determine the approximate Global Warming Potential (GWP) of media consumed, we utilized emissions factors from two well-known sources. The first being the proprietary EcoInvent life cycle database published by the Swiss Center for Life Cycle Inventories. EcoInvent data utilized represent cradle-to-gate impacts for paper production, which are not inclusive of GWP due to carbon sequestration in printed matter, decomposition of paper discarded to landfill, or forest carbon loss.

Additional GWP data were taken from the Environmental Defense Fund *Paper Calculator* [5]. Our understanding of EDF's tool is that it does consider life cycle impacts beyond the cradle-to-gate data we used from EcoInvent. As could be expected with a more inclusive system boundary, emissions factors derived from the EDF Paper Calculator were two to three times as large as the EcoInvent factors.

It is important to note that there is some debate among industry and scientific experts regarding the GWP of paper and similar wood fiber-based products. An in-depth examination of the various points of view is beyond the scope of this paper. Thus, we chose to utilize available data that we found to be authoritative and representative of different perspectives. Differing GWP data would move our estimates in proportion to their variance from the factors we utilized.

We applied available GWP factors for various media types to printing applications on a best-fit basis. For example, we assumed magazines were printed on a mix of coated groundwood and coated free sheet (also known as *wood containing* and *wood free* papers, respectively) and direct mail was printed on uncoated free sheet. Print volume and GWP factors were multiplied to yield an approximate GWP for each digital and analog portion of a print application.

B. Print Application GWP

In order to estimate the system GWP for twenty-nine different print applications, we needed to make some simplifying assumptions. We assumed that total GWP for a given application is in rough proportion to the paper GWP for that application. We also assumed that proportion is approximately the same across different applications.

Our literature search yielded several studies that assessed the life cycle GWP for printing applications. Among others, we relied on a study conducted by The Carbon Trust, which assessed the GWP of the UK's Daily Mirror newspaper, and the assessment of digital imaging equipment conducted pursuant to the European Union's Energy Using Products Directive, which assessed home and office inkjet and laser printers [6]. Our interpretation of those studies revealed that the contribution of paper to the overall life cycled GWP of those very disparate print applications was approximately 70%. Thus, we utilized that figure to estimate the overall GWP for each print application, increasing from the calculated paper GWP.

C. Addressable GWP

Some infrastructure is required regardless of the type of printing technology utilized, including buildings, some distribution, retail locations, and other overhead. To account for this "fixed" GWP, we assumed that the GWP addressable through digital efficiency was 90% of the total calculated as described above. Based on most printing life cycle analyses that we have reviewed, this is a very conservative assumption.

D. Rank Ordering Printing GWP Sources

An examination of the results of GWP modeling revealed that over 80% of GWP was concentrated in just six print applications, Newspapers, Office Productivity, Magazines, Books, Retail Transactions, and a catch-all "Other" category. 99% of the overall GWP is accounted for with 18 of the 29 different print applications considered (see Figure 1).

For assessment of abatement potential we considered the top 18 applications, which represented 99% of the estimated total GWP.

E. Abatement Potential

Our estimates of the potential for abatement through digital efficiencies were based on published findings and HP research about the benefits of flexibility inherent in digital applications, which allow print service providers to target content to users and complete shorter print runs profitably. Digital technology also enables a print-on-demand strategy, helping to minimize overruns. We also considered the potential to minimize start-up losses (commonly known as make-ready in the printing industry).

The different abatement potentials were applied sequentially, in the order of (1) targeted content; (2) minimizing overruns; and (3) reduced make-ready. Applying the abatements in sequence, rather than against the same baseline, ensures we use the addressable GWP at each step and so avoid double counting. We describe these routes to abatements in more detail below.

1) Targeted Content

Targeted content and distribution means personalizing, customizing or regionalizing the material being printed. It is well known that material targeted by gender, age, language or special interest group offers an improved return on investment. In other words more can be done with fewer pages. A personalized newspaper for instance could leave out articles of no interest to a particular reader. Analog presses cannot easily produce personalized work but on digital presses every job, or even every page, can be different.

In consideration of the challenges presented by changing established business models, distribution methods and other factors, we applied a very conservative overall abatement potential of 10% of the total GWP to the following print applications: Newspapers; Magazines; Catalogs; Inserts; Brochures, pamphlets and flyers; Direct mail and Directories.

2) Minimizing Overruns

As noted above, digital technology can enable a print-on-demand strategy. Our research indicates that overruns are driven by current distribution and publication business models, such as the need to avoid premature sellout at newsstands or retail distributors. Additionally, overruns are driven by the relatively high cost of printing short runs on analog equipment. For example, recently published research by industry analyst InfoTrends, found a crossover point (the quantity of prints at which analog printing cost per page becomes less than digital printing cost per page) to be 22,096 for Postcards and 1,871 for Newsletters (12,761 and 7,484 impressions, respectively) [*source 10*]

Reductions in overruns could be achieved by reducing the cost of short runs through application of digital technology. Overruns could also be reduced by deploying presses closer to the point of demand and distributing publications to them electronically. Digital presses that can, for example, satisfy daily newspaper demands of a city, a district or a single retail outlet are being developed and will enable this distribute and print strategy. Digital technology can also reduce overruns by lowering the cost of short runs,

To estimate the abatement potential due to minimizing overruns, we relied heavily on returns figures for newspapers, magazines and books.

- Newspapers: 20% [1]
- Magazines: 50% [7]
- Books: 30% [8]

In the absence of data, we applied an abatement potential of 20% to other printing applications.

3) Reduced Make-Ready

A recently published study by the Rochester Institute of Technology study observed "It is … generally understood that digital processes require little or no makeready, and that the print-on-demand philosophy minimizes overruns (extra copies that are not needed)." [9] In contrast, color registration and other make-ready processes associated with analog technology consumes a significant amount of paper.

While the study is limited in scope, the comparison of make-ready waste it contains is instructive. The authors recorded a wasted sheet count of over 1000 sheets with a lithographic (analog) press for both a short and long print run, while the comparison waste sheet count with a digital press was significantly less, 24 pages for a short run and 600 sheets for a long run (the long run included a misfeed). This equates to a range of 10% to over 70% less make-ready with digital technology, as a percentage of total paper consumption for the long and short runs, respectively.

Of course, set-up losses become less significant for high volume print runs. However, the trend in the printing industry is towards shorter print runs. [10]

To model the potential benefits of reduced make-ready with digital technology, we used a reduction potential of 5% for newspapers and magazines and 20% for other print applications.

4) Abatements to Office Productivity Printing

Office productivity printing, a significant source of paper consumption, is almost universally accomplished with digital technology. A variety of strategies is being successfully employed to make office printing more efficient and reduce waste. Example strategies include user authenticated printing, which prevents jobs from being requested, but never picked up at the printer. Industry analyst Gartner observed that, "users could reduce ad hoc printing costs by 10% by implementing PIN [or code] authenticated system." [11] Setting printer to print in duplex, or two-sided mode as a default, is another easy-to-implement strategy to reduce paper consumption. Devices capable of scan and send functions can enable digital workflows, reducing the need to print. In addition to paper savings, an optimized printing infrastructure can yield substantial energy savings—HP has observed 30% to 80% reductions with some Manage Print Services customers.

HP is undergoing an internal "Print Transformation" program, with anticipated reduction in paper consumption of 25% over a 2006 baseline. We used that figure to estimate abatement potential for office productivity printing.

V. Results and Discussion

A. Results – Global Printing Carbon Footprint for 2020

We examined a broad range of print applications and ranked them by carbon footprint. To do this we used volume figures from many sources (to be enumerated in the full paper) normalized to A4 page equivalents. We then used conversion factors from EcoInvent [12] and the Environmental Defense Fund [13] to turn these into CO_2 equivalents. Starting with the biggest emitters we analyzed the amount of GHGs generated by each. Figure 1 shows the ranked results and also shows the extent to which the global printed page volume is mostly produced on analog presses.

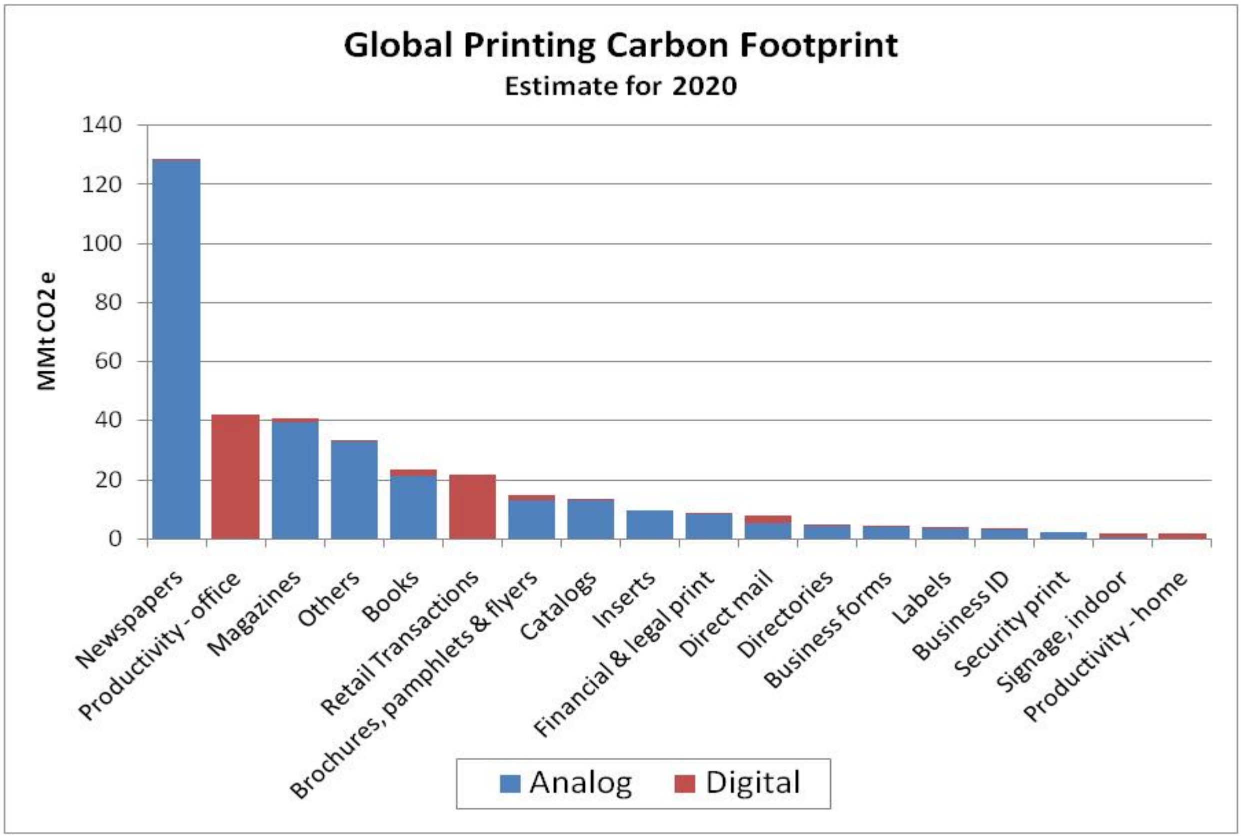

Figure 1: Global Carbon Footprint of print applications, modeled using EcoInvent database

B. Results – Abatement Potential

Table 1 describes potential direct and innovative GHG abatements we have identified for digital print technology. Utilizing the EcoInvent database factors for GHG emissions due to paper we obtain a saving of 114 $MMtCO_2$ eq per annum. Using the more inclusive figures of the Environmental Defense Fund we obtain 251 $MMtCO_2$ eq per annum.

It is instructive to put this potential into perspective with other actions identified by the authors of the Smart 2020 report [3]. The potential for abatement we have identified is very significant: our low-end estimate is roughly equivalent to the abatement the Smart 2020 report gives for broad implementation of lighting automation. Our high-end estimate is close to the Smart 2020 abatement figure for extensive implementation of telecommuting.

C. Discussion – Model Sensitivity and Impact of Assumptions

The intent of the work presented here is to examine the potential to reduce the global carbon footprint of printing through the application of more efficient printing technology. Thus we present a more detailed investigation than that contained in the most significant prior examination of GWP abatements potential of information technology and communications: the Smart 2020 report, which was never intended to be an exhaustive analysis of global printing applications

Reduction Method	Application	Reduction Potential %	Reduction Potential ($MMtCO_2$ eq)	
			EcoInvent Database	EDF Factors
Minimize Overruns	Newspapers [1]	20%	21	53
	Magazines [9]	50%	17	38
	Books [7]	30%	10	10
	Other	20%	17	39
Reduce Setup Losses	All	News/ Mags:5%; Others: 20%	22	49
Targeted Content & Distribution	Newspapers, Magazines, Catalogs, others	10%	18	44
Managed Print Environment	Office Productivity	25%	9	18
	GRAND TOTAL		**114**	**251**

Table 1: Direct and Re-engineered business model GHG abatements

Of course, any analysis of this type is highly dependent upon assumptions. We presented the basis for our assumptions in Section IV. Variance from our modeling assumptions would in most cases correlate to proportionate increases or decreases in our estimated print application GWP and abatement potential. For example, a greater GWP of uncoated free sheet than we assumed here would result in a proportionate increase in the footprint and abatement potential for a number of print applications.

Some assumptions have a more controlling influence on our model than others. Scaling up from an estimated paper GWP to arrive at an overall print application GWP is a significant simplification. For long run, paper intensive applications, such as newspapers, this assumption may lead to overstatement of the relative impact of the printing operation and distribution. For lighter production applications, such as home printing and possibly some retail (receipt) printing, paper is likely a much smaller proportion of the GWP, so our simplifying assumption probably leads to a substantial understatement of the applications overall GWP.

Another critical assumption is the application of current CAGRs through 2020 to arrive at an estimate printing volume. Of course, changes in printer and end user behaviors, disruptive technologies and external market factors could all have huge influence on those growth rates.

Recognizing the shortcomings of a model looking a decade into the future, our analysis does highlight the very important role that digital printing technology can play in reducing GHG emissions due to paper consumption and printing operations.

D. Verification framework

We have identified the very significant GHG abatement potential of re-engineered print business models which reduce paper waste. Realizing this potential by using digital presses to implement the methods of section IV will require testing in practice. However, print applications exist in an agro-industrial system which produces new paper and recycles old. It is important to ensure these new digital print solutions do in fact result in net emissions reductions without resulting in unanticipated adverse impact. We also need to be sure that the carbon debt of digital press roll-out is quickly exceeded by the abatements. Furthermore, although digital presses are replacing analog in many applications, they still account for only a small fraction of the global print volume – around 10%. We intend to monitor deployments through links with HP production divisions. To validate the financial cost and GHG emission savings of these new digital solutions against traditional analog print we will use two generalized models. The first, shown in Figure 2 below, allows us to simulate the entire paper and print ecosystem under varying regimes of forestry practice, wood pulp and paper production, printing, delivery and distribution, recycling and disposal.

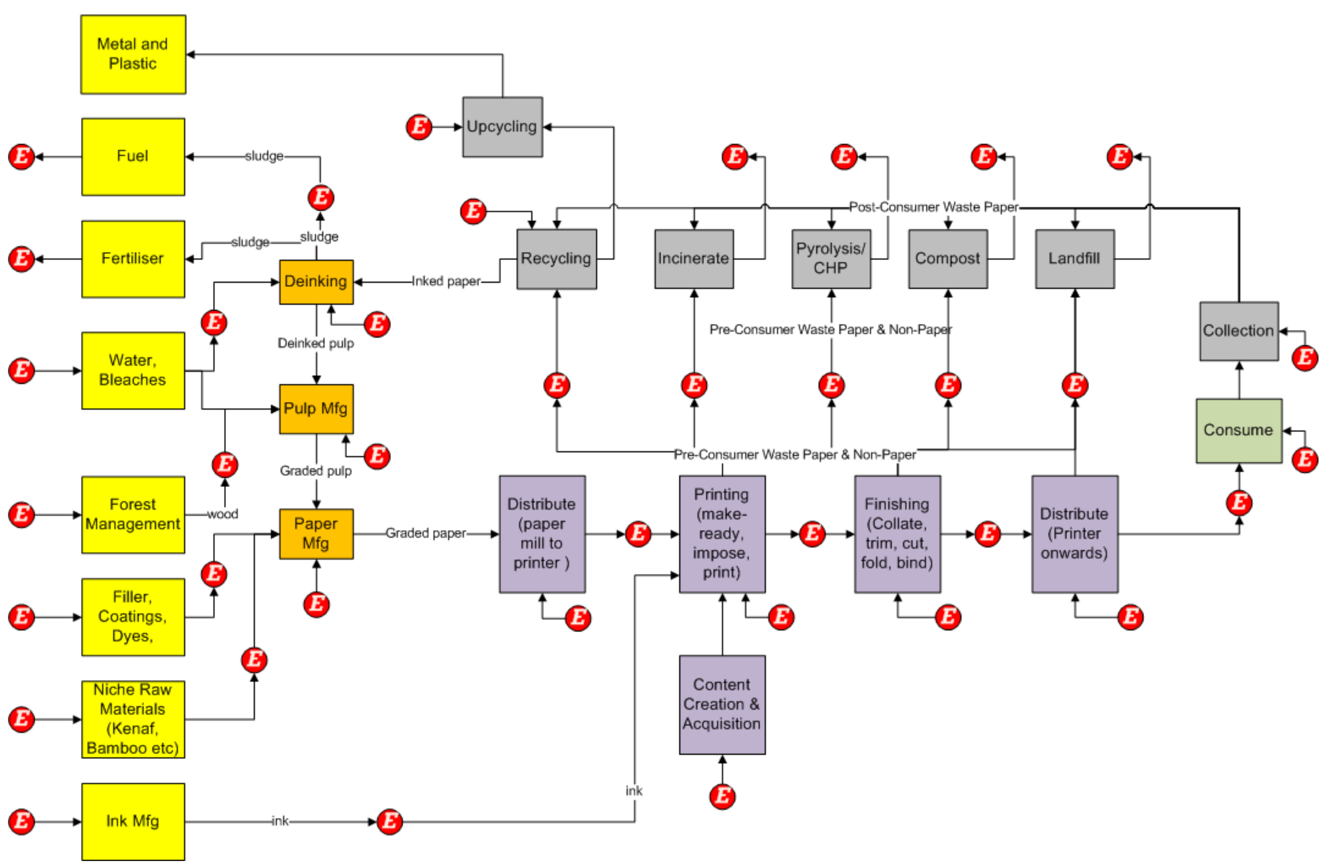

Figure 2 The Generalised Print Ecosystem Model

Note that this model can take account of all aspects of printing from trees to recycling and explicitly represents the energy inputs at each stage. Emissions due to a particular step, such as forest management can be accommodated alongside their primary energy consumption.

The second model allows detailed simulation of the paper and printed product distribution and delivery stages for any print application. The second model is in fact a component of the first, reflecting an aspect of that model that we wish to focus on with increased magnification. Figure 3 shows a schematic of the detailed production and distribution model.

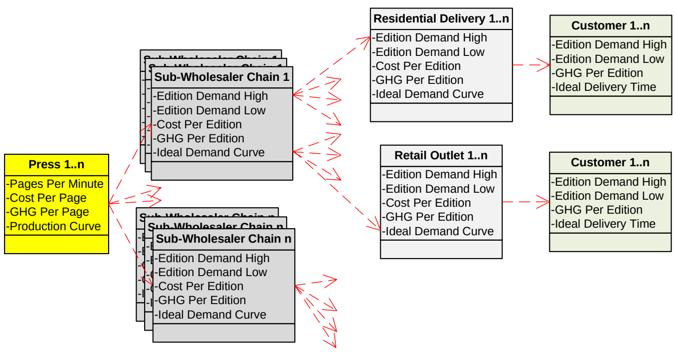

Figure 3 The Production and Distribution Model

Note that this model can cope with any deployment of analog or digital print production facilities (e.g. a centralized factory or a distributed network of presses) and can capture any distribution system to customers: postal and retail methods of final delivery to the customer are highlighted in the schematic. The distribution model must be able represent several kinds of function such as delivery of fresh paper to the presses, delivery of printed product from the presses to the retail channel or customer, and collection of obsolete product.

We will validate the methods described in section IV using the two models described above. Accurate modeling will guide the design of solutions and make it possible to choose between competing digital press deployment schemes.

VI. CONCLUSIONS AND RECOMMENDATIONS

We have quantified the potential for digital print technology to reduce direct GHG emissions of the most significant print applications and to further reduce emissions via evolved business models. The magnitude of potential abatements is substantial, on the order of 114 to 251 $MMtCO_2e$ – at the low end similar to the Smart 2020 [3] report's estimate for global implementation of automated lighting systems, and at the high end almost as great as the same report's estimate for a large scale shift to telecommuting. While some abatement strategies will be straightforward to implement, such as making duplex printing the default in offices environments and customizing content with digital printers, other actions will require systemic change, such as reducing the proportion of newspaper and magazine newsstand unsold returns. In order to monitor and document progress, we have produced a modeling framework that will enable us to evaluate digital press deployments aimed at realizing these abatements. In future work we intend to describe in detail transformations enabled by digital presses, and the magnitude of the reductions realized. We will use our modeling tools to validate the benefit of the transformations in the wider print ecosystem.

In addition to validating our assumptions and refining abatement estimates, we recommend that future research on this topic examine the benefits of digital technology applied to printing on packaging. We did not include packaging in this study because although it is a very large print application it has a different primary purpose to others we identified. We have yet to develop a model for the abatement potential of digital technology applied to packaging. We also recommend continued research comparing the life cycle impacts of paper and electronic media.

REFERENCES

[1] 2007 Circulation Facts, Figures & Logic. An NAA Resource for Circulation Performance Standards. Newspaper Association of America. 2007. Available at: http://www.naa.org/Resources/Products/2007-Circulation-Facts-Figures-Logic.aspx

[2] Carbon footprints in the supply chain: The next step for business. The Carbon Trust.London, UK. 2006. Available at: http://www.carbontrust.co.uk/Publications/publicationdetail.htm?productid=CTC616

[3] SMART 2020: Enabling the low carbon economy in the information age. The Climate Group/Global e-Sustainability Initiative. London, 2008. Available at http://www.smart2020.org/

[4] Counsell, T. A. M. and Allwood, J. M., "Reducing Climate Change Gas Emissions By Cutting Out Stages In The Life Cycle of Office Paper". *Resources, Conservation and Recycling*,49 (2007) 340-352

[5] Emissions data derived from Environmental Defense Fund Paper Calculator during November 2008. For more information visit http://www.papercalculator.org.

[6] L. Stobbe, 'EuP Preparatory Studies "Imaging Equipment" (Lot 4)" Task 1 through Task 8 Final Reports. Fraunhofer IZM. Berlin, Germany. 2007 -2008

[7] H. S. Matthews, E. Williams, T. Tagami, C. T. Hendrickson, "Energy Implications of Online Book Retailing in the United States and Japan". *Environmental Impact Assessment Review.* Vol 22, Issue 5, October 2002, pp. 493-507

[8] Magazine industry figures. See: http://www.magazine.org/advertising/handbook/Magazine_Handbook.aspx

[9] S. Kadam, M. Evans, S. Rothenberg, "A Comparative Study of the Environmental Aspects of Lithographic and Digital Printing Processes", A Research Monograph of the Printing Industry Center at Rochester Institute of Technology, PICRM-2005-01, Rochester, NY, May 2008 (Sponsored by the Printing Industry Center at RIT, of which HP is an industry partner)

[10] S. Adoniou & J. Hamilton, "The Cost of Color Print Revisited", InfoTrends Strategic Assessment, Weymouth, MA, 2008 (Report commissioned by HP)

[11] S. McNee, K. Weilerstein, "Cost Cutting Intiatives for Office Printing". Gartner Research. February 2008

[12] http://www.ecoinvent.ch/

[13] Environmental Defense Fund**.** Updated Lifecycle Environmental Charts from Chapter 3 of the Paper Task Force Report. Available at: http://www.edf.org/documents/1687_figures.pdf