22 Paper

Paper is a natural product—closely related to trees—so its energy and emissions impact can be surprising: energy is mainly needed to convert trees to a lignin free wet pulp, and then after papermaking to remove excess water by evaporation. Are there other efficiency options, or can we reduce demand for paper?

The British spend their time swapping wordplay jokes that no one understands, hopping on and off red buses, making calls from red telephone boxes, posting their letters in red pillar boxes, and eating their chips from read newspapers. It's the newspapers that concern us here—although of course, Belgian bureaucrats have stopped our material efficiency strategy of eating chips from used newspapers in case the pungent prose in the print is infectious. Presumably now that newspaper sales are slumping, due to the fall in demand for re-use in catering and the rise of electronic alternatives, we'll soon be eating our chips off used eReaders as everybody who bought one last year has to upgrade to this year's eReaders 1.01. After that someone will have to deal with all the chips in the eReaders...

In applying our story to paper, we need to know who's using it, what for, and whether the recent decline of newspaper sales in Europe and the US tells us anything about demand for paper overall. We need to find out what's driving energy use and emissions in making paper, and then we can look at options such as eReaders which might allow us to live well with less paper.

The properties, uses and production of paper

We'll start with current uses of paper. The pie chart[1] in Figure 22.1 shows that the largest categories of use are container board (corrugated cardboard used in boxes and shipping containers), printing and writing paper (including uncoated papers used in photocopiers, laser printers and books, and coated papers employed in magazines and brochures), newsprint and other types of paper and board employed in packaging. The quality of paper is determined by its optical properties (colour, brightness, whiteness, opacity), resistance to light and ageing, moisture content and 'printability' (smoothness, ink absorption, curl and friction) when used for printing, and by its strength and stiffness when used for packaging, among many other properties.

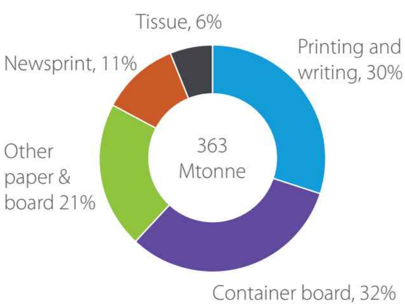


Figure 22.1—**Final uses of paper in 2005**

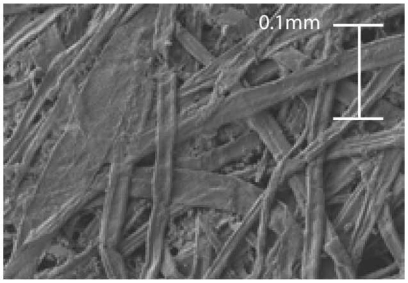


Figure 22.2—**Magnified picture of conventional office paper**

A paperless office?

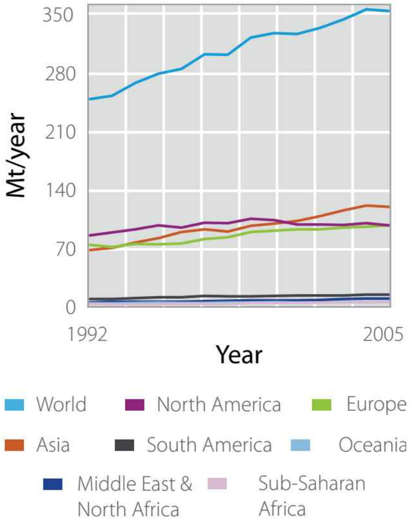


Figure 22.3—**History of paper demand from 1992–2005**

Figure 22.2 shows a sample of conventional office paper in which you can see intertwined wood fibres covered by fillers such as clays and sizing agents. Older papers were made from cotton fibre, or other textiles, while most contemporary paper is made from wood, particularly softwood from conifers (e.g. pine) and hardwood from broad-leafed species (e.g. oak). However, any source of fibre can be used to make paper—and we have samples made from bamboo, hemp, abacá, grasses and even elephant dung (a favourite in the 9 year old boys market segment). To create a smooth surface for printing and to improve optical properties and printability, paper is often 'filled' with kaolin clay, calcium carbonate, titanium dioxide, silica or talc. The strength of the paper is generally determined by the length and origin of the wood fibres (softwood length of 3-7 mm adds strength while hardwood length of 1–2 mm adds bulk and thickness). Cardboard is generally brown because it is mainly made out of unbleached brown wood fibres. Papers for magazines and brochures are coated, generally with kaolin clay and calcium carbonate in order to improve gloss and whiteness. Tissue paper has special strength, water absorbency, appearance and comfort characteristic achieved by controlling pulp quality and additives.

In 1981, when one of the first modern workstation computers known as the Xerox Star was designed to replicate some aspects of paper use, the idea of the 'Paperless Office' was born—and the death of paper has been predicted ever since. In fact the reality has been very different, and to date our enthusiasm for paper has only increased: having a printer in every home, we use more and more paper, as we urgently share important prose and images with each other. Figure 22.3 shows the global history of paper demand from 1992 until 2005[2], with demand broken down by major region. In parallel, Figure 22.4 shows consumption of paper against gross domestic product (GDP) per person in 1995 and 2007 for selected countries[3]. These two images show that demand for paper has steadily grown, with the only modest decline in consumption being in North America, specifically in the US since the last presidential election, mainly due to declining newspaper sales (presumably because there is less need to discuss the behaviour and characteristics of President Bush). Despite this small decline and slow European growth, global demand has increased considerably as a result of high demand growth in Asia. Consumption of paper in Belgium is significantly higher per person than elsewhere in Europe (due to a national commitment to writing annoying directives on chip wrappings and other subversive national traditions), and Figure 22.4 shows that there is some link between wealth and paper consumption. Although growth rates in developed countries vary, their consumption per person is much higher than that observed in developing countries such as China, Brazil and Indonesia. Both

Trees on their way to paper making

figures also show that the paperless office has remained a dream—with economic growth comes demand for more paper.

Although we could make paper from almost any source of fibre, in reality we use trees. Trees and trees and trees, that is. A typical oak tree weighs approximately a quarter of a tonne when chopped down (dry mass)[4]. If it is destined for paper making, the limbs are removed and the trunk is driven to the pulping mill. On average, 24 trees are required to make a tonne of printing and writing paper[5], so the paper consumption of 110 million tonnes of printing and writing paper reported in 2005 required around 2.6 billion (thousand million) trees. Planted at a density of 100,000 trees per square kilometre[6], that requires an annual harvest of 26,400 square kilometres of trees—just less than the total area of Belgium. However, this is for printing and writing paper only. If we assume that all 363 Mt of paper consumed in 2005 was of this type of paper, we would have required nearly 3 Belgiums. Oak trees are usually at least 20 years old when lopped, so in total, at a rate of 3 Belgiums per year, we would cut down 60 Belgiums before the first oak harvest recovers, and this is roughly 1.2 % of earth's land area. Paper making requires a lot of trees and a lot of land.

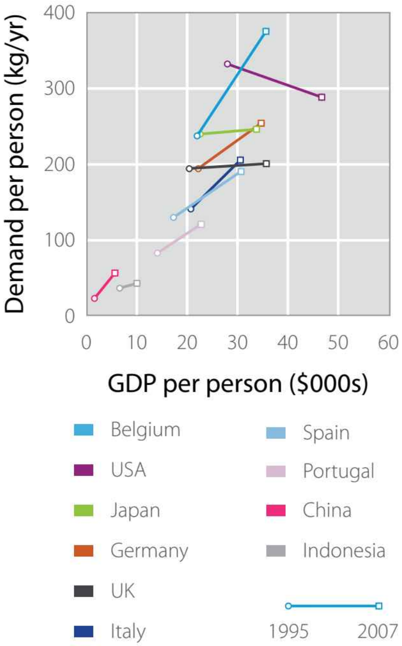


Figure 22.4—**Paper demand vs. GDP per person, 1995-2007**

Converting a tree into paper has two main steps. Firstly we need to break down the structure of the tree to extract the cellulose fibres we want to use. In a living tree, cellulose fibres, which are strong in tension, are bound together by lignin, an organic polymer that resists compression. Paper can be manufactured with or without lignin depending on the pulping process used. In mechanical pulping, cellulose fibres are extracted from the wood by pressing and grinding. Paper made in this way is weak and discolours easily when exposed to light due to its high residual lignin content. A stronger paper less prone to discolouration is produced by chemical pulping. In this process the cellulose fibres are extracted and converted into pulp by dissolving the lignin with a chemical/water solution in a high pressure steam cooker. The resulting mass, containing a mix of pulp and black liquor (liquid residues of chemicals and dissolved lignin) is sent for pulp washing where the pulp is separated. The pulp is in some cases dried and transported—high-tree countries like Finland sensibly want to capture the most possible value from their tree harvest, so supply dried pulp to low-tree countries, such as the UK, for rehydrating and paper making. (In fact, in the UK, although we harvest approximately 9 million tonnes of roundwood each year mainly in Scotland, we also import roughly 8.5 million tonnes of pulp and paper[7]). The second stage of the process begins with this pulp, by now relatively pure cellulose fibres in water, mixes into it the fillers and other additives needed to create required properties and then 'lays' the pulp onto a fine mesh. This miraculous process is well worth

Wet end of a paper making machine

Dry end of a paper making machine

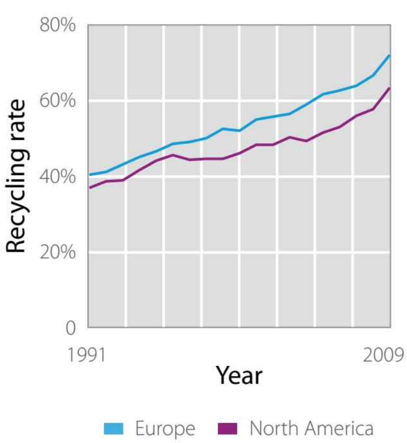


Figure 22.5—**Paper recycling rates in the USA and the EU**

watching if you ever have the chance to visit a paper mill: what appears to be a milky fluid pours onto a moving conveyor of fine mesh; the water drains through and may be squeezed out with a roller, to the point that a wet fibrous sheet can be transferred from the mesh to a hot roller. The remainder of the process is to evaporate excess water from this wet sheet. This must be well controlled so that the moisture content is uniform across the paper, and is achieved by winding the continuous feed of wet paper over a long chain of hot rollers. Eventually a huge roll of paper is wound up, and may then be coated before being cut to final sizes.

Paper recycling is of course widely practised, and we get better at it each year. Figure 22.5 shows estimates of recycling rates in the United States and European Union[8], showing that in the bigger paper-using countries (the richer ones) recycling rates are around 63-73% and improving steadily. When we throw our old newspapers and book drafts into the recycling bin, they're collected into bales, and then sent to a 'pulper' containing water and chemicals. Here, the paper is cut into small pieces and the mixture is heated to help separate the cellulose fibres and form the pulp. The slushy mixture of pulp is then forced through screens with holes of different sizes and shapes to remove contaminants such as glues or other alien materials. Generally the quality of pulp made from recycled papers is lower than that of virgin pulp, because the fibres have been shortened in the recycling process and may have been weakened. Recycling of coated papers is more difficult due to the layer of polymer covering the fibres. Heavy contaminants such as staples are removed from recycled pulp by spinning inside conical cylinders. Glue, old print and adhesives are removed by de-inking in which air and surfactant chemicals are injected into the pulp so that ink particles separate from the pulp and attach to air bubbles which can be removed easily from the mix. The pulp is squeezed dry and residual water is commonly reused.

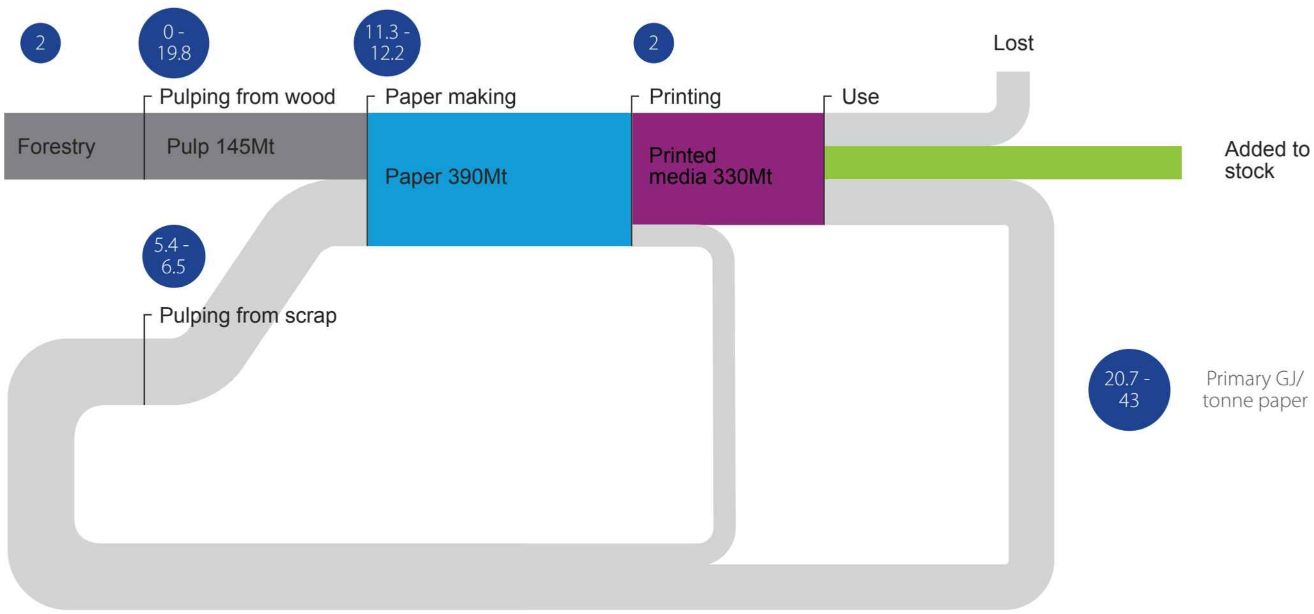
Energy and emissions in paper making

We have of course created a Sankey diagram[9] to show the global flow of materials through the paper production process to final products, and the diagram also shows current energy requirements per unit of production for the main processes. Making a tonne of paper from recycled old paper uses between 18.7–20.7 GJ while making it from trees requires 15.3–36 GJ, depending on the manufacturing processes used. However, converting this diagram into one showing emissions is difficult—for several reasons in addition to the usual ones related to data availability, not knowing the range between average and best practice, and understanding the mix of fuels used in generating grid electricity. For paper, our additional challenges are:

- Plant scientists do not yet know the net emissions effects of planting, growing and harvesting a tree, due to the complex effects of soil disruption.
- A substantial fraction of the energy used in paper making, particularly from primary wood, is generated by burning the trimmings from the trees, and the 'black liquor' which is the by-product of pulping.
- Because recycling shortens the fibres, most recycled paper actually has a reasonable fraction of virgin paper to increase its strength or smoothness.

We've therefore found a wide range of estimates for carbon emissions in paper making. Making a tonne of conventional office paper from trees leads to emission of around 0.7–1.2 tonnes of CO_2/tonne of paper, while using recycled pulp, this figure changes to 0.6–0.7 tonnes of CO_2/tonne of paper. However, it is quite possible that some recycled paper has actually led to more emissions than paper from trees—because of the use of biomass (which over its whole cycle does not emit significant CO_2 emissions) in generating energy for primary processes.

Figure 22.6—**Sankey diagram of paper production**



Paper with one eye open

Figure 22.7[10] shows that fuel and electricity purchases accounts for around 11% and 7% of the costs of making paper respectively so, naturally, the pulp and paper industry is highly motivated to adopt every possible energy efficiency measure. Their achievement is clear in Figure 22.8[11]—showing that energy inputs per tonne of paper have improved year on year, but as we have seen with all materials, they appear to be approaching an asymptote. The key steps taken to achieve recent improvements have been the application of bio-refineries to produce fuels, chemicals, power and materials from biomass, adoption of best available technology and the development of new technologies such as black liquor gasification (to produce gas from spent pulping liquor for use in boilers) and new drying technologies (that increase the drying rate). As with all our analysis, don't know to what extent further improvements are possible by raising average to best practice, but assume some improvement remains.

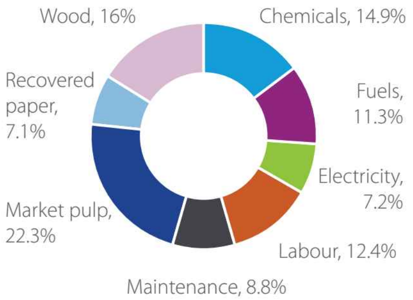


Figure 22.7—**Costs in paper making in Europe, 2006**

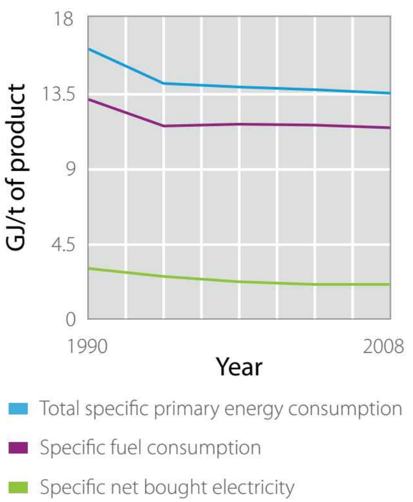


Figure 22.8—**History of energy consumption in paper making**

The other strategies being pursued in the industry are to increase the use of biofuel, to pursue CCS, to make better use of waste heat from the process, to produce on-site electricity and heat by combined heat and power (CHP) generation, and to improve the recycling loop.

Primary paper making already makes good use of the biomass from its own waste products and in Europe we have estimates that up to 54% of energy requirements for paper making from pulp are provided in this way[12]. This biomass is combusted to generate heat or electricity. Further substitution of biomass for other fuel forms however raises the same problem we have identified before: it takes a lot of land to create enough biomass to replace fossil fuels. So given other competition for land, it seems this will only make a small contribution. Direct fossil fuel combustion in papermaking is used to provide other energy, so the two candidates for pursuing CCS are to use it directly with furnace exhausts, and to purchase electricity from sources with CCS attached. Given the doubts we've already expressed about CCS, and as the paper industry is not making a significant push in this direction, this doesn't seem a priority.

However, the paper industry has made significant efforts to combine their generation of heat and power. The logic of so-called combined heat and power (CHP) generation is that gas or coal fired power stations create significant waste heat while generating electricity, so potentially the heat could be used as well as the electricity. Potentially this approach applies well in paper making, as most heat is required to cause evaporation in the paper drying process—say at 150–200°C, and this is a relatively low temperature compared to the waste heat released by power stations (typically up to 540°C for some condensing power plants) so there's a good match between supply and demand.

Improving the recycling loop for paper has three objectives: increasing the rate of waste paper collection (i.e. avoiding the loss of paper to landfill or incineration); using less energy to pulp recycled paper; improving the yield of recycled pulp by improving the separation of ink and other contaminants from the used paper. The earlier graph on recycling rates showed that we are generally improving collection rates worldwide, but there is a limit: tissue and sanitary paper obviously cannot be recycled, and some paper is kept in archives; 80% recycling rates appear a realistic limit[11]. The yield of recycling, currently limited by paper fibre shortening and the difficulty of separating clean fibres from contaminants, could be improved by replacing the caustic chemicals used in de-inking with less damaging materials and by the design and adoption of inks and adhesives that could be removed more easily.

A survey of forecasts on future paper-making shows that paper demand may be 2.4 times greater by 2050 than in 2008, and over this period it might be possible for the paper industry to reduce its emissions by 40% per unit output if all best practices are applied[12]. This is an incredible reduction but not enough to reach our 50% absolute reduction target by 2050.

Paper with both eyes open

In a crisis we could give up a lot of paper use easily and with little inconvenience: we could rapidly switch from purchasing individual copies of magazines, newspapers and books, to shared use; we know that we could live with less packaging. However, our exploration about a future with both eyes open, aims to look for ways to continue to deliver the services we obtain from paper, while using less of it. We've found four examples of material efficiency for paper: using lighter paper; printing on demand; removing print to allow paper re-use; substituting e-readers for paper. Let's take a look at each in turn.

Most of the paper we use in computer printers and photocopiers has a weight of 80 grams per square metre. This gives it a satisfyingly stiff feel when we turn pages, and is sufficiently opaque that printing on both sides does not create interference. Could we manage with 72 grams per square metre? It's easy to find out: you can purchase 70gsm paper for use at home, and as far as we can tell it has the same function as 80 gsm, albeit a little less stiff. So, are confident that, if we wanted to, we could save at least 10% of global demand for office paper with lighter weight selection and presumably we could approach that figure in other applications.

A problem for newspaper suppliers is that we buy them in physical form, and if we can't find a particular brand on a particular day, will rapidly switch to an alternative. Despite this, each newspaper lasts for only one day, and then has no value. So the newspaper business must always print too many copies of each day's paper because the commercial risk of running out is far greater than the cost of printing an excess. The same is true of books sold in shops. This over-print is collected and recycled, but that as we've seen has an energy cost. So the idea of 'print on demand' has been around for many years with the hope that we can avoid the excess by printing rapidly whatever the customer really wants. The technology exists for us to do this, even for bound books, but we haven't yet adopted the practice. There are a few possible reasons for this: print-on-demand books are normally slightly more expensive, they have a reputation for lower print quality and readers may be unfamiliar with print-on-demand brands.

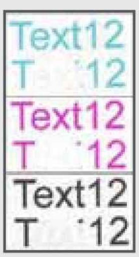
In chapter 15 we looked at the opportunity to re-use steel sections in construction without melting them—so how about paper? Most of the paper we discard in offices is undamaged and we discard it only because we don't want to read what's written on it. We were struck by this possibility some time ago, so both Tom Counsell and David Leal have studied for their PhDs in our lab to see if we could find a way to "un-print" used paper[13]. Can we design a front end to a photocopier that would take in yesterday's discarded printing, and clean off the print so that we can then put on today's print? We decided early on to limit ourselves to existing conventional uncoated paper and conventional toner because it would be harder to introduce a system that required either of those to change. We initially examined three options for toner removal:

- rubbing it off with sandpaper worked well, particularly with fine paper moving at high speed across the paper and under light pressure, but although we could remove the print, we couldn't avoid thinning the paper also;
- we found a range of chemical solvents that would remove the toner without damaging the paper, but the safety requirements for the solvents were demanding, and we couldn't imagine installing this approach in an office;
- laser ablation worked to some extent, and removed the print, but the paper under the old print was discoloured in the process, and could still be read.

We've now focused on this last approach, and after searching through a wide range of possible laser settings, can now remove the print effectively and leave the paper undamaged. We're rather proud of this work, so have put a box story below with more detail: potentially using laser ablation to remove print looks like a route that might save some paper in future.

Finally, aren't we about to abandon paper altogether and instead read books, magazines, newspapers and all other documents on electronic screens? This is back to the dream of the paperless office, but has apparently become more of a reality as portable computer screens become lighter and better, light emitting polymers enter the market, and hand-held speciality readers take off. We don't know the answer: sceptics tell us that people buy a new electronic device in addition to all the paper they buy anyway, while enthusiasts tell us that the dip in US paper consumption in Figure 22.3 is not after all because of President Bush's departure, but because of eReaders gaining strength. However, we can look at two aspects of the question: are newspaper sales being affected by e-readers, and what are the environmental consequences of substituting e-readers for newspapers?

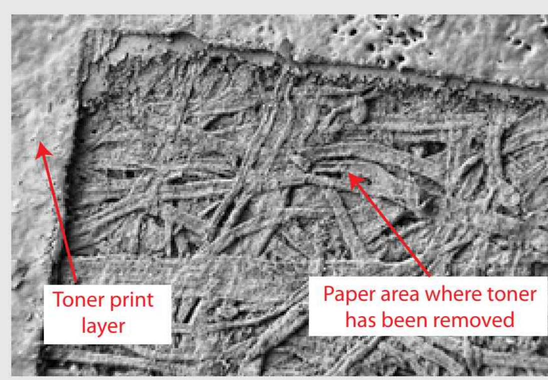
Unphotocopying



Unfortunately, designers of toner-print are very good at their job: toner adheres to paper so strongly that it is easier just to get rid of the used sheets of paper than reuse them.

The toner used in typical black and white office printers is a composite material formed by a polymer and a black pigment, commonly a polyester resin and iron oxide respectively. Just like any other opaque material, black toner-print absorbs light, particularly visible light, and specifically, it absorbs more than 95% of green light. If a concentrated green laser beam is fired onto toner, it will raise the temperature. The polymer in the toner will melt, or if the temperature is increased further it will evaporate, detaching the rest of the toner components from the paper. If at the same time the laser energy can be chosen below the ablation or evaporation threshold of paper, paper can be cleaned and re-used instead of being recycled or buried in landfill. We have found that this is possible by using very short pulses (less than a few nanoseconds long) of concentrated green laser light and can remove text from paper without causing any apparent damage to the paper under the print.

The image shows a highly magnified picture of a trial in which we ablated a square in an area of continuous black print. In comparison with Figure 22.2, the revealed paper is close to its original condition.



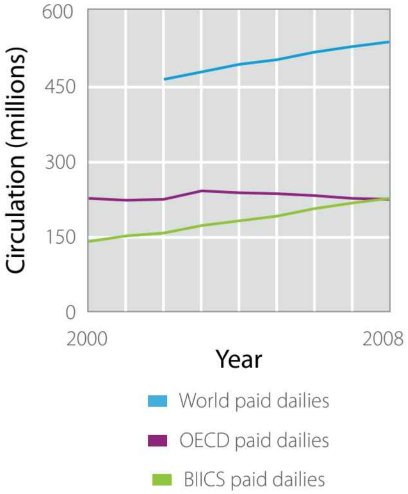


Figure 22.9—**Circulation of newspapers in OECD and developing countries (Brazil, India, Indonesia, China and South Africa)**

Newspaper sales in developed economies are declining. Figure 22.9[14] shows that sales are growing rapidly in developing nations such as Brazil, India, Indonesia, China and South Africa (BIICS), as economic development expands the number of potential buyers. But in OECD member nations such as the US and other European countries, newspapers sales are declining. In parallel, Figure 22.10 shows that the number of people reading newspapers online has grown rapidly[15], so it seems possible that the decline in physical newspaper sales is indeed driven by a substitution of electronic screens for paper (and not just a paucity of factual content as you might suspect). We have not yet seen figures that give evidence about whether electronic reading is changing book print runs.

We have a pretty clear answer to our first question, but unfortunately the second is much more difficult. Comparing the environmental impact of buying books or newspapers as opposed to reading on a screen depends so strongly on your assumptions, that you can easily create any answer you like: how much paper is saved by the electronic screen? How many aspects of the production and disposal of either the screen or the printed paper can be accounted for meaningfully? How do you compare the different environmental impacts of a micro-electronics and paper? All these questions are unanswerable, so although we've found many studies on this topic, we're unsatisfied by their conclusions. Over time, we'll find an answer to the question by watching what happens to paper demand and demand for screens at some meaningful geographical scale—say that of a country. Until that happens, the comparison is theoretical only. However, we can make a few important observations on what happens to electronic waste, at the end of its life. We've seen that paper recycling is effective, and rates are growing. Unfortunately, electronics recycling is not effective, and ought to be a national scandal in developed countries. Recent EU legislation on the take-

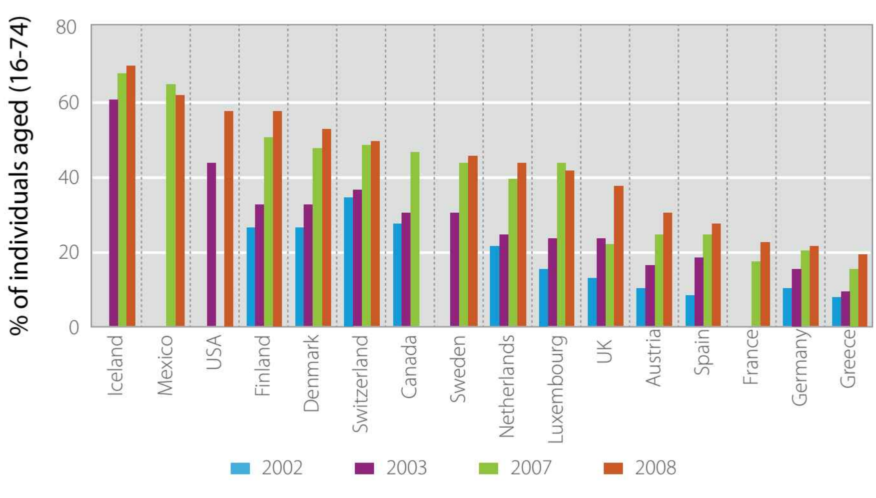


Figure 22.10—**Trends in readership of online newspapers**

Electronics recycling in India[18]

back of electronic goods has reduced the flow of electronic waste to landfill in the EU, but places no burden on manufacturers to deal with their own waste—it is estimated that only one-third of e-waste is treated in line with the EU Waste Electrical and Electronic Equipment (WEEE) directive[15]. Some of the rest is illegally exported to Africa and Asia. In India, some of the poorest people in the country purchase an open bucket of sulphuric acid, and use it in their main living room to extract precious metals from electronic waste. When the acid has lost its strength, it is simply dumped along with the other unwanted material in open ground nearby. The photo is a sombre reminder of this consequence of our enthusiasm for replacing electronic gadgets so frequently, and is unnecessary when companies such as Umicore[16] have the technology to process WEEE safely near to the original point of discard.

So the jury's out on electronic screens replacing paper—we simply don't know if any substitution is really happening, and can't work out the environmental consequences until a measurable shift in national statistics occurs. However, we have seen that we can reduce total paper production without loss of service whether by light-weight paper, print on demand, or un-printing, and let's not forget our great and undervalued libraries as a perfect opportunity for extending the useful life and increasing the service intensity of printed paper.

Outlook

Paper production is already energy efficient, and recycling already operates well but could get better. There are some opportunities to improve efficiency, and there are opportunities for supplying the same service with less total paper production. How does all that add up?

Global paper demand is around 390 million tonnes per year[11] and a survey of forecasts[17] anticipates that demand will have grown by 164% by 2050 compared to 2005. Our survey of potential carbon emissions reduction suggests we might save 40% of emissions per unit of output if we increase global recycling rates to 81%, and apply all possible energy efficiency best practices for the production and recycling of paper and pulp. With demand growing, this isn't enough to reach our target of a 50% absolute cut in emissions. So using less paper through material efficiency or demand reduction is an inevitable requirement for meeting the target, and we've got some exciting opportunities to go and pursue it. We could even make a start by eating our fish chips out of used European Directives!

Notes

The properties, uses and production of paper

1. Forecasts conducted by the RISI (2007).
2. Based on data from the Food and Agriculture Organization of the United Nations (FAO), 2007.
3. Elaborated with data from EIPPCB (2010).
4. Estimated with data from the Technical Association of the Pulp and Paper Industry (TAPPI)—http://www.tappi.org/paperu/all_about_paper/earth_answers/earthAnswers.htm
5. Thompson (1992) refers to a calculation that, based on a mixture of softwoods and hardwoods 40 feet tall and 6-8 inches in diameter, it would take a rough average of 24 trees to produce a ton of printing and writing paper, using the kraft chemical (freesheet) pulping process".
6. Recommended oak planting density across the state of Illinois in the US: 108,000-135,000 trees/km^2.
7. Based on statistics from the forestry commission (2011).
8. Data from American Forest and Paper Association, 2010 and Confederation of European Paper Industries (CEPI), Key Statistics, 2009.

Energy and emissions in paper making

9. Elaborated with data from Paper Task Force (1995), Hekkert, M.P., E. Worrel, 1997, Nilsson et al. (1995), de Beer (1998), Ahmadi et al. (2003).

Paper with one eye open

10. EIPPCB (2010). Reference Document on Best Available Techniques in the Pulp and Paper Industry. European Integrated Pollution Prevention and Control Bureau, Institute for Prospective Technological Studies, European Commission's Joint Research Centre, Seville, Spain.
11. Confederation of European Paper Industries (CEPI), Key Statistics, 2009.
12. Forecast figures from IEA (2008) and Martin et al. (2000).

Paper with both eyes open

13. Key articles on Paper Un-printing: Counsell and Allwood (2006) review 104 patents filed mainly since the mid 1990s that propose technologies to recycle office paper within the office, without destroying the mechanical structure of the paper. Counsell and Allwood (2007) consider how to reduce emissions from cut-size office paper by bypassing stages in its life cycle. The options considered are: incineration, localisation, annual fibre, fibre recycling, un-printing and electronic-paper. Counsell and Allwood (2008) present a feasibility study on the use of an abrasive process to remove toner-print used in laser-printers and photocopiers. Counsell and Allwood (2009) report on experiments that investigate the use of solvents to allow black toner print to be removed from white cut-size office paper. Leal-Ayala et al. (2010). In this article, lasers in the ultraviolet, visible and infrared light spectrums working with pulse widths in the nanosecond range are applied on a range of toner-paper combinations to determine their ability to remove toner. Leal-Ayala et al. (2011) analyse the applicability of ultrafast and long-pulsed ultraviolet, visible and infrared lasers for toner removal. Current work is focused on performing a feasibility study comparing the quality of all proposed solutions, their environmental implications, economical feasibility and commercial potential.
14. Based on research into the evolution of news and the internet (OECD, 2010).
15. As reported by BBC News (Lewis, 2010).
16. Umicore operates an integrated smelter and refinery which is capable of recovering 17 metals (Au, Ag, Pd, Pt, Rh, Ir, Ru, Cu, Pb, Ni, Sn, Bi, In, Se, Te, Sb and As) from distinct e-waste products such as printed circuit boards, ceramic capacitors, integrated circuits and other components contained in small electronic devices such as mobile phones, digital cameras and MP3 players. More info can be obtained from Hagelüken (2006).

Outlook

17. The IEA (2008a) estimate that primary and recycled paper and board production in 2050 will increase by 2.49 times to an overall consumption of 950 Mt (p.503, 164% increase from 2005). This projection is considerably higher than previous IEA projections, where the potential gains from the digital economy and tighter waste policy were overestimated.

Images

18. Photo by Empa