**Technical assessment for**

**RECYCLED PAPER**

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# Executive Summary

Paper and paperboard are an essential global commodity that require finite forest resources to produce. As global annual paper production has exceeded 400 million metric tons and consumption is projected to grow in the next 30 years, a resource-conserving and less environmentally impactful method of production is required to satisfy this demand. In this study, recycled paper and paperboard are assessed for their financial feasibility and greenhouse gas reduction potential as compared to conventional paper produced from virgin sources. Adopting the use of recycled paper and paperboard products, as part of a portfolio of materials reduction solutions, are a necessary aspect of avoiding further greenhouse gas emissions in the future.

Recycled paper is a form of used paper that contains post-consumer paper that been re-processed after usage and disposal in place of virgin pulp, thereby reducing the amount of virgin material harvested. In this a study, an analysis of the impact of recycled paper has been conducted through literature review, data analysis, and financial and supply/demand projections.

Through the analysis conducted in this report, recycled paper has been found to be a beneficial materials reduction solution that results in between 2.5 and 3.5 Gt CO2,eq emissions reduction over a 30-year period (2020-2050). It has an associated CO2,eq ppm reduction of between 0.34 and 0.44 ppm by 2050. These emissions reductions come from increasing the current paper recovery from an estimated rate of 55%, which correlates to about 38% of paper being produced from recycled fibers globally, to an estimated global maximum of between 67-73% recycled content. The emissions reductions were calculated as the difference between these adoption scenarios to a status quo, “reference case” where adoption remains at 38% of the projected total addressable market. The climate reduction potential of recycled paper has been determined through measuring the indirect CO2,eq emissions associated with recycled paper production vs. conventional paper production. On average, recycled paper produces about 56% CO2,eq emissions than conventional paper when considering both direct and indirect emissions.

Recycled paper additionally has environmental benefits beyond what are modeled in this study, including avoiding disturbing habitats and species in managed timber regions, avoiding releasing chemical pollutants into nearby waterways through its production process, and using less water in its manufacturing process. However, recycled paper requires traditional energy sources to be produced, as nearly all recycled paper is produced in traditional paper mills, alongside conventional paper. Despite this disadvantage of paper manufacturing, research indicates that environmental benefits can be amplified through paper mills adopting renewable energy sources to further reduce greenhouse gas emissions.

Implementing recycled paper, however, is a challenge due to the higher costs associated with manufacturing paper with recycled content. This is due to several factors, including costs of collection and recovery, transportation, quality control, and consumer preferences. The financial analysis conducted in this study reveals that recycled paper currently is more expensive to purchase than conventional[[1]](#footnote-1). The financial analysis conducted here-in determined that, on average, paper with recycled content ranging from 30-100% costs $219 more than purchasing 1 metric ton of the same quality, type, and grade made from virgin material.

In order for recycled paper to be implemented globally, the paper market and consumer preferences must change. Although global paper demand is projected to increase in the next 30 years due mostly to population and GDP growth, consumer demand for newsprint and other printed media is rapidly changing with product substitutions from electronic media. In mature markets globally, paper consumption and demand have been declining annually, while emerging markets still see growth. In order for recycled paper to achieve its known environmental benefits and contribute to global greenhouse gas emission reductions, the significant financial costs of adoption must be factored into any adoption strategies and weighed against its climate and environmental benefits.

# Literature Review

## State of Recycled Paper

Paper and paperboard are a global product produced by chemical and/or mechanical processing of wood pulp extracted from virgin timber. Virgin timber is harvested in a variety of ways globally, from sustainable, third-party certified managed forests (which account for less than 10% of forestry globally) to clear-cutting or other methods. Virgin timber causes significant environmental impact but currently is essential to supply the global demand for paper and wood products. Once timber is harvested, wood pulp is extracted from the timber and then manufactured into several types of paper products including coated and uncoated mechanical office/copy paper, newsprint, magazine/catalog paper, containerboard, tissues, and others. Paper products are then used and discarded, either via landfilling, incineration, or recovery. Recovered paper and paperboard products (referred to as ‘recycled paper’) are a materials reduction solution that includes any form of commercially produced paper product that has been re-processed. The production process of paper includes its entire lifecycle from virgin timber harvesting to paper use, disposal, and recovery.

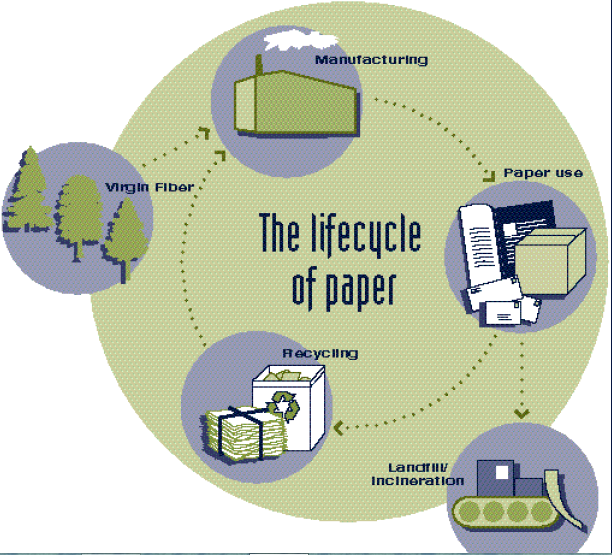


Fig 1: The lifecycle of paper. (EPA, 2012)

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Fig 2: Diagram of the paper production process. (Environmental Paper Network 2013)

Paper can be produced through a chemical process, known as kraft pulping (which produces brighter paper from softwood pulp), where-in pulp is ‘digested’ at a high temperature and pressure and cleaned in chemical solution of sodium sulfide, sodium hydroxide and other chemicals. It can likewise be produced through a mechanical separating process where pulp is separated through a mechanical refining and grinding process; or a combination of mechanical/chemical in order to separate the pulp fibers, clean, and de-contaminate them.

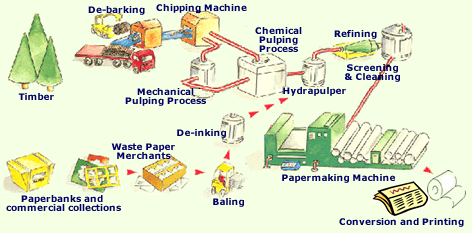


Fig 3: Illustration of paper-making process. (http://www.paper.org.uk/information/pages/papermaking\_process.html)

Recycled paper occurs at the last stage of this production process where-in used paper, i.e. post-consumer waste, is collected, sorted and processed. The recovered paper products, once cleaned and processed, can be re-made into pulp for manufacturing new paper products. Recycling of paper requires virgin fiber acquisition, as pulp can only be processed several times before its fibers (known as lignans) break down; paper fibers are recycled an average of 2.4 times. (Environmental Paper Network, 2018) Re-using post-consumer paper, however, reduces the amount of virgin fiber harvested by acting as a substitute for virgin pulp. Current studies estimate that for production, between 67-73% of fiber can be from waste paper, and that the rest needs to be supplied by virgin fibers, a critical technical substitution limit (Van Ewijk et al, 2018).

By substituting for virgin fiber, recycled paper reduces paper mills’ environmental impacts by not depleting wood resources, disturbing the habitats and species in those regions, not releasing bleach or chemical pollutants into rivers and waterways, and by using less water in its manufacturing process (SCS Global, 2015). Recycling one short ton of paper saves 3.3 cubic yards of landfill space, and can use up to 68% less energy than production of virgin paper (ISRI, 2019). Recycled paper, however requires electricity (drawn from both renewable and non-renewables sources depending on the facility), transportation, collection, and processing resources to produce. Furthermore, recovered paper and paper products cannot be used to produce new paper products at a 1:1 weight ratio, due to processing losses and technical limitations, in fact the average global substitution rate is 1.5 (Van Ewijk et al., 2018). Although recycled paper has an environmental impact, primarily through its grid energy requirements, research indicates that it is less environmentally harmful than virgin paper (Kinsella, 2012) and may play a significant role in reducing greenhouse gas emissions from the manufacturing industry globally.

## Adoption Path

### Current Adoption

Paper recycling is an active and growing aspect of materials management that has varying levels of adoption globally. Global production of paper is growing in some parts of the world, due in part to the increasing consumption demands of emerging economies including China, India, and several African countries. Total global paper and board consumption was 423.3 million tons in 2017 (CEPI, 2018), up from 403.6 million tons in 2013 (CEPI, 2015). In North America, Western Europe, Japan and other developed economies, total paper consumption has declined per capita annually since 2009.

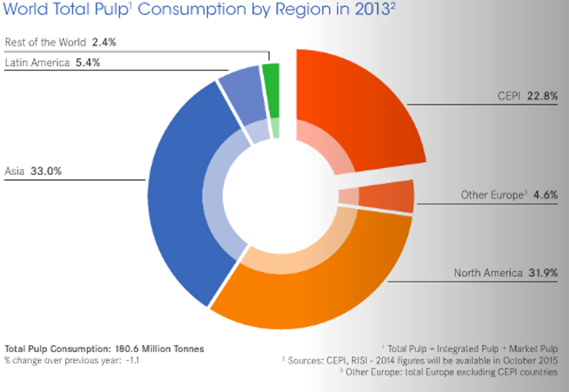
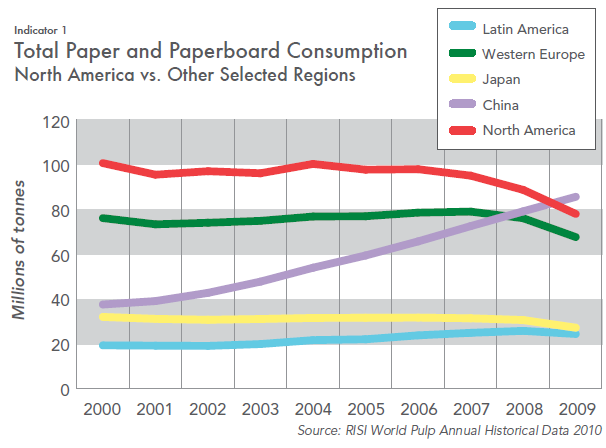


Fig. 4: Regional paper and paperboard consumption trends (RISI, Inc. 2009)

Fig. 5: World Total Pulp Consumption by Region in 2013. (Confederation of European Paper Industries 2014)

Some regions have established formal paper recycling collection, sorting, and manufacturing programs, while other regions, such as Africa and Eastern Europe, have less formal paper recovery technologies and generally incinerate or landfill more post-consumer paper than recover it (EPA, 2012). The current global recovery rate of paper is estimated around 54%, with some regions, like parts of northern Europe, reaching 75% paper recovery rates, while others, such as the parts of Asia and Africa, averaging around a 47% recovery rate. Again, because collection, or recovery, does not translate at a 1:1 ratio for replacement of virgin fiber, the global 54% collection rate can also be translated to a 38% recycled input rate, or recycled content (Van Ewijk et al., 2018).

### Barriers to Adoption

Increasing the paper recovery rate globally, requires, firstly, a decrease in the cost of recycled paper. From a consumer’s perspective, recycled office paper costs more per metric ton to purchase than conventional paper made from virgin sources . These values are highly variable, however, with costs of recovered paper having a range of over $100/ton in only one country (China), and more expected variability globally (Li et al., 2020). There are several factors that may affect this variability and price differential between virgin and recycled products, including but not limited to, the additional costs to install and build paper recovery facilities in places where virgin paper manufacturing infrastructure have been built previously, lack of demand due to perceptions of recycled paper’s poor quality (Waste & Resources Action Programme 2010), transportation and external costs, which are shown to be between 21-24% of total life cycle cost of paper products (Li et al., 2020).

### Trends to Accelerate Adoption

The changing demand of paper will likewise affect recycled paper’s adoption rate. Global paper demand is projected to increase in the next 30 years due mostly to population and GDP growth (Turner et al. 2010), despite changing consumer demand for newsprint and other printed media with the substitution effect from electronic media. The consumption of paper is positively correlated with GDP, but in mature markets, this consumption is declining: in the U.S., for example, 2017 consumption of paper was 69 million tons, down from 71 million in 2013 (FAO, 2017) and 75 million tons in 2010 (FAO, 2014). There exists a high degree of uncertainty in these predictions, as increasing digital media trends are predicted to continue in low-income countries and therefore paper demand may decrease, particularly emerging paper-consuming countries like China, India, Brazil and Russia (Hansen 2013). As other economies enter into the paper market, they experience higher per capita growth rates of consumption for a period of time, until a stagnation of demand (P. McCarthy et al. 2010). Despite these qualifications, global consumption of recovered paper is increasing, it was 236 million tons 2017, or 57% of market, where it was only 220 million tons in 2013, which was 56% of the market in that year.

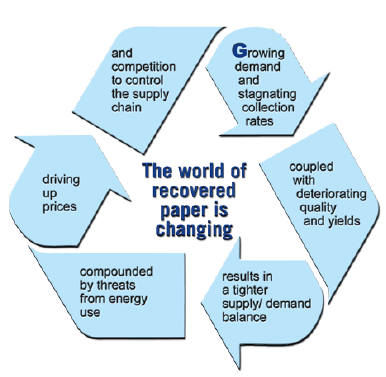


Fig 6: The changing supply chain of recover paper. (Poyry Management Consulting 2013).

Unfortunately, projecting paper demand and production, and thus future paper recycling rates, is difficult due to the volatility of the several economic factors, such as GDP, which becomes increasingly unreliable over longer time periods (Hansen 2013) as well as the lack of long-term, reliable, and global historical data on forest resources, trade flows, and substitution of paper for electronic media and its effect on the market. The world of paper production is changing, and with it, the capacity for recycled paper to reduce greenhouse gas emissions.

## Advantages and disadvantages of Paper Recycling

On average, paper recycling produces less greenhouse gas emissions than conventional virgin paper production (ISRI, 2019; Sevigne-Itoiz et al., 2015). It additionally reduces impacts on forests, thus avoiding de-forestation and its associated negative environmental impacts, which include an immediate release of carbon into the atmosphere (Climate for Ideas, 2013), avoids releasing carbon dioxide and methane emissions from landfilling, and does not emit hazardous substances from incinerators. It additionally avoids disturbing habitats and species, and releasing pollutants from manufacturing into waterways (SCS Global Services, 2015). Overall, it produces less greenhouse gas emissions than virgin paper according to a study conducted by the Environmental Paper Network:

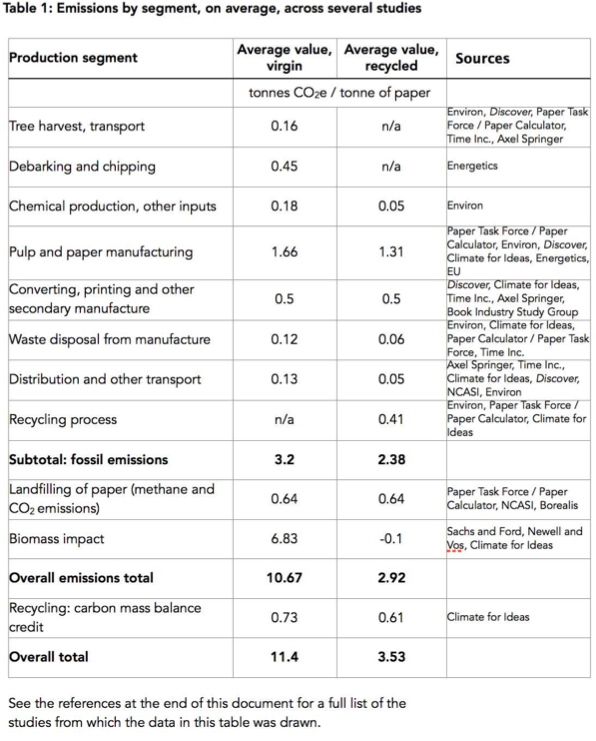


Fig 7: Greenhouse Gas Emissions From Recycled vs. Virgin Paper. (European Environmental Paper Network, 2010)

Of note, however, is the similarity between emissions numbers when not considering biomass impacts (in Figure 7, see Subtotal: fossil emissions of 3.2 vs. 2.38**).** The literature reviewed varies in its accounting for the biomass impacts of paper production.. The difficulty is clearly assessing these indicators, but this may count as an advantage for virgin paper. The life-cycle analysis depicted below found that depending on the boundaries of the life cycle analysis, energy required (in GJ per ton) as well as CO2,eq emitted (in kg CO2,eq per ton of paper produced) varied significantly dependent on fuel source. In Figure 8 below, there is a comparison between the three paper production processes which depicts ‘100% chemical’ as the least environmentally harmful. In the adjacent figure, however, these same results have been modified with ‘unlimiting resources’ (allowance of biomass as a fuel source) and ‘limiting resources’ (does not allow biomass as a fuel source). Here it depicts ‘100% recovered’ as the less emitting when biomass as a fuel source is taken into account. These figures demonstrate, that a) depending on the inclusion of biomass as a fuel source changes the emissions outputs and b) that recovered paper produces far less kg CO2,eq per ton of paper produced as compared to mechanical and chemical production processes.

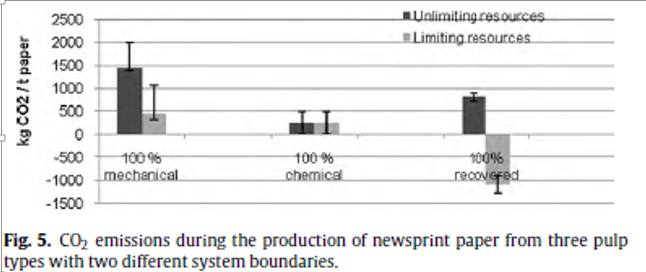
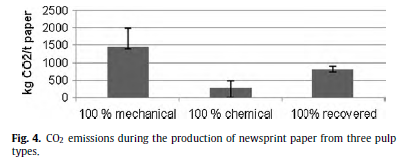


Fig 8: CO2 emissions during production of newsprint by 3 different pulp production processes. (Laurijssen et al., 2010)

However, recycled paper requires the same fuel sources that virgin paper facilities require, that is, traditional grid-supplied energy. If paper mills are not using renewable energy (wind, hydro, nuclear) or producing their own and converting it to steam (biomass), then they are using traditional non-renewable sources which contribute to emissions. This is a disadvantage of all paper manufacturing. Additionally, all paper making requires the associated transportation, distribution, printing, and ‘retail emissions’ associated with a consumer product. Even recycled paper is not wholly ‘carbon neutral’ (Canopy Planet.org).

A disadvantage of recycled paper is that continues to be more expensive for the average consumer than conventional paper as evidenced through the financial analysis conducted in the model. Post-consumer paper, ranging from 30% to 100% recycled content, varies in price drastically depending on the quality of paper considered, but recycled paper goods costs more than virgin paper of a comparable quality and quantity. The changing nature of the paper industry will determine how prices react in the future, depending on global supply and demand, but as consumer awareness grows and the desire for ‘green’ products increases, the potential for recycled paper to have a larger market share increases.

# Methodology

## Introduction

Project Drawdown’s models are developed in Microsoft Excel using standard templates that allow easier integration since integration is critical to the bottom-up approach used. The template used for this solution was the Reduction and Replacement Solutions (RRS) which accounts for reductions in energy consumption and emissions generation for a solution relative to a conventional technology. These technologies are assumed to compete in markets to supply the final functional demand which is exogenous to the model, but may be shared across several solution models. The adoption and markets are therefore defined in terms of functional units, and for investment costing, adoptions are also converted to implementation units. The adoptions of both conventional and solution were projected for each of several scenarios from 2015 to 2060 (from a base year of 2014) and the comparison of these scenarios (for the 2020-2050 segment) is what constituted the results.

## Data Sources

## Total Addressable Market

In order to determine the potential for recycled paper to act as a global adoption solution, determining the market and capacity for implementation was required for this research. The total addressable market (TAM) in this situation was the total production of paper produced annually globally and in nine pre-selected Project Drawdown regions. Determining the markets relied on a combination of primary and secondary sources, assumptions, and projection equations used in the Microsoft Excel software.

Determining the base and current year TAM relied on data provided by the United Nations Food and Agriculture Organization (FAO) statistics and extrapolations and interpolations from other data sets. Annually, FAO produces a report that includes individual countries’ paper and paperboard production and consumption rates within its analysis of forestry production and trade. From the years 2015 and prior, this data provides reliable indicators of future rates and projections. The FAO stats were used and averaged with other data to provide base 2015 rates, in million metric tons produced, as individual countries could be selected in order to generate the data appropriate for Project Drawdown’s selected regions for comparison.

Projecting the total addressable market from 2015-2060 required using data from industry and academic research. Some regions’ projected markets are based on statistical consulting company RISI, Inc.'s paper production projections through 2030, or McKinsey & Co projections of paper market growth every 25 years (McKinsey, 2013), or a POYRY report from 2013 (POYRY, 2013). Other sources, including the Confederation of European Paper Industry (CEPI, 2014 and 2018), Buongiorno’s Global Forest Projection Model (REF), and a paper by Johnston about the decline of print media due to internet adoption (Johnston, 2016) were included to calculate an average TAM. The annual values were projected through 2050 assuming a scenario where paper and paperboard consumption grew according to these projections.

In some cases, industry reports provided market production data for certain years, such as 2015, 2020, and 2030. Determining the rates at the years in between those provided required using data interpolation to determine growth rates and capacities per each year. Where projections were not available to 2050, the growth rates through the most recent years (2030 in many cases) were projected to continue to 2050. These projections are based on conservative estimates and present a conservative depiction of market growth.

## Adoption Scenarios

Two different types of adoption scenarios were developed: a Reference (REF) Case which was considered the baseline, where not much changes in the world, and a set of Project Drawdown Scenarios (PDS) with varying levels of ambitious adoption of the solution. Published results show the comparison of the PDS to the REF, and therefore focus on the change to the world relative to a baseline. Adoption, in this instance, is considered to be the amount of paper products produced globally in any given year from recycled fibers. This is different than “collection rates” or even “recovery rates”, which typically refer to the amount of waste material at end of life collected for recycling. Due to processing losses as well as incorrect sorting, the amount of material collected for sorting is not the same as the amount that ends up becoming goods for use again. This quantity is referred to sometimes as the Recycled Input Rate (RIR), or Recycled Content to differentiate from end of life collection. Adoption was calculated by using the more readily available collection data and multiplying by a material loss rate to estimate recycled content.

### Reference Case

The global and regional adoption scenarios vary widely and rely on consistent collection rates as projected by the literature. In order to assess the feasibility of paper recycling, it is important to first consider the overall growth rate of the waste paper production, and then determine the current and future paper recovery rates. Projected waste paper production rates were collected regionally, with particular attention paid to changing rates over time. Data for these projections came from FAO, industry reports, the CEPI, EPA, Union of Concerned Scientists and peer-reviewed academic literature. The growth rates per region are as follows:

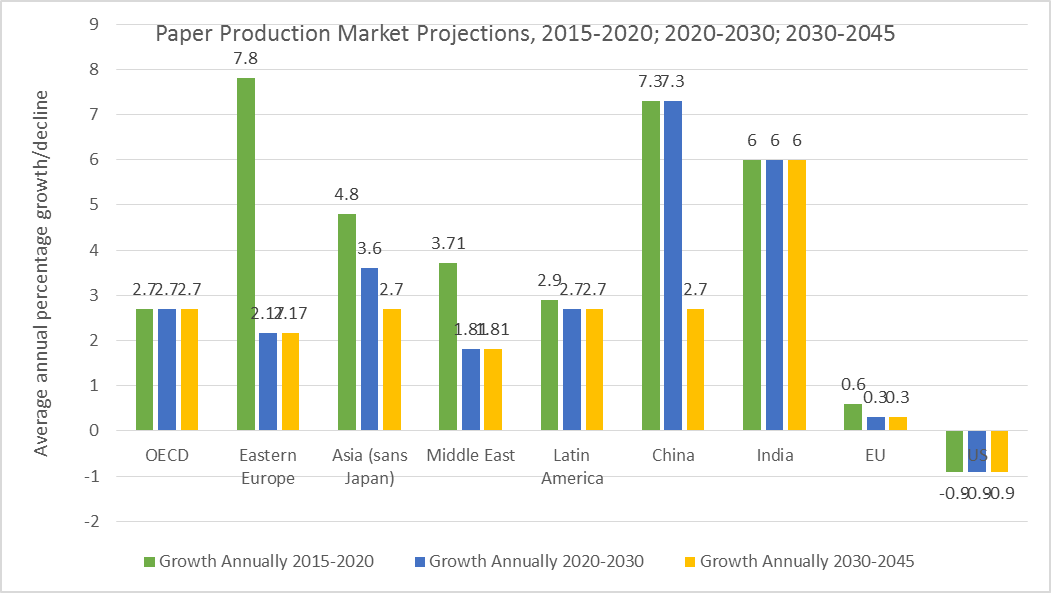


Fig. 9 Author’s chart gathered from literature review.

Though there is variability in production rates in each period depending on the region, nearly every region demonstrates a decline in production over time, or a stagnation, to their projected economic growth and consumer demand. More developed areas, such as the EU and US, show evidence of dematerialization, where production saturates and then stagnates or even declines.

### PDS Scenarios

The second aspect of calculating the adoption path scenario is the current and projected rates of adoption of recycled paper, not just the overall paper production. The current global paper recovery rate is around 55% -this corresponds to a 38% recycled input rate - , with Western Europe leading with nearly 75% recovery (primarily due to established infrastructure in Scandinavian countries) and India, Eastern Europe, China, and other Asian and Middle Eastern regions trailing (Buongiorno et al. 2003). This is primarily due to the lack of formal paper recycling, collection, sorting, and processing facilities in those regions as well as the informal incineration and landfill disposal methods used currently. The Middle East & Africa, Eastern Europe, and Latin America are predicted to increase gradually, but their share of recycled paper will largely depend on their production rates, population growth, and associated economic factors like GDP per capita increasing accordingly. Estimates indicate that between 67-73% of paper production can be met using recycled fibers, the upward technical limitation of the recycled input rate.

For this reason two adoption scenarios were developed, one which follows a medium rate of adoption increase and is bounded by a 67% technical limit to recycled input, and another which follows a high rate of adoption increase and is bounded by a 73% technical limit to recycled input. These adoption cases are based on the collected data and projections from FAO (2018) using Western Europe’s recovery rate as a reasonable goal for global recovery, POYRY projections (PORYR, 2013), McKinsey and Co (2013) prognostications, and a Union of Concerned Scientists (2014) study. These recovery rates were then converted to RIR rates using the ratio of recycled fiber collected to new paper produced.

## Inputs

### Climate Inputs

(Indirect emissions) Climate inputs analyzed included direct and indirect CO2,eq emissions for recycled and conventionally produced paper products. The unit of measure was the metric tons of CO2,eq equivalent produced per metric ton of paper produced. In order to determine these emission factors, a literature review was conducted through industry, scholarly, and non-profit sources. In order to achieve consistency, all measurements were converted to metric tons. Emissions due to paper manufacturing process are analyzed as direct emissions. Emissions from all other life-cycle stages of virgin and recycled paper production are analyzed as indirect emissions. This includes transportation and distribution, upstream energy consumption, material acquisition and processing, such as the initial timber harvest (and the associated CO2,eq emissions due to this process of habitat disturbance and de-forestation). Some sources attempted to trace these emissions through every process, while others only measured emissions at the manufacturing stage, i.e. when mills received pulp and then processed it to produce recycled or virgin paper. Due to inconsistencies in reporting and system boundary definitions from all sources, emissions for transportation and distribution are calculated separately, and then added to any indirect emissions data that does not include these stages. These total indirect emissions are then added to direct emissions.

Life cycle stages that are not included in either direct or indirect emissions include landfilling virgin paper (possible CH4 emissions) and the biosequestration impacts of conserved forest. End of life management of virgin paper has implications considered in other waste solutions, and land use change and carbon sequestration of forests are considered in biomass models, so they are excluded here so as to not be double counted.

Two important findings were identified when looking at climate impact data. First, according to some sources, virgin paper produces less CO2,eq emissions than recycled paper. This is due to the use of a liquid pulp by-product, termed ‘black liquor’, that is suitable for combustion through the Tomlinson process in place of traditional fossil fuels such as coal or natural gas (Climate Tech Wiki). The primary emissions stemming from recycled paper is the energy requirements to operate the paper mills that produce it and thus using black liquor allows a mill to generate a significant portion of its energy requirements renewably. The paper industry reports a 33% decrease in GHG emissions due to increasing black liquor use (63% of energy consumed for manufacturing pulp and paper in 2011) (Environmental Paper Network 2011). Black liquor, according to the EPA, is not included in greenhouse gas emission calculations thus lending mills the opportunity to claim ‘zero net emissions of carbon’ when burning black liquor/wood fuel as their fuel source. In several studies, mills that produced virgin paper reported declines in fossil fuel use, while black liquor use increased. Second, the majority of emissions associated with recycled paper stem from a mill’s energy requirements. Sources that used data from the Netherlands, Norway, and Sweden all found recycled paper to produce significantly less CO2,eq emissions than comparable mills using recycled pulp in other regions. This may be due to the availability of renewable energy sources, such as hydro, nuclear, and wind that these mills use. If one were to exclude these energy sources and rely on traditional coal or natural gas sources, it may be the case that recycled paper production actually emits more greenhouse gases than virgin paper. However, other studies found that when comparing virgin fiber from three different mills to recycled office paper, that the climate impacts of the post-consumer recycled office paper were less than 1% of the impacts associated with the virgin paper production process. The same study concluded that although virgin papers required more energy overall to create, some of the energy required comes in the form of black liquor which do not qualify as GHG contributors. The recycled paper studied was found to have been produced using non-renewable energy sources and thus contributed higher GHG emissions (New Leaf Paper/SCS Global 2015).

Sources additionally report on different types of paper, including coated copy, uncoated copy, newsprint, cardboard, catalog paper, for which the manufacturing process may differ slightly and thus contribute varying levels of emissions. For example, current waste paper stream consists of around 56% of containerboard and/or corrugated products, 9% newsprint, 7% tissue, 5% printing and writing and the remaining 23% other type of paper. Furthermore, emissions associated with production of recycled paper varies due to the different recycled content of the paper. Data is included for paper with ranges from only 30% recycled content, to 100% recycled content. All the data that were collected for different types of products and recycled content were included and averaged (using a weighted average, where possible) to represent the heterogeneity of the paper market.

### Financial Inputs

In order to determine the financial aspects of adopting recycled paper globally, research was conducted regarding the first and operational costs of recycled paper manufacturing. However, due to both a lack of data as well as a desire to remain consistent with the functional unit (million metric tons of paper produced) first cost was defined as product cost to the consumer. Financial research focused on the first costs of purchasing paper by the consumer. In this case, the agent considered was a paper consumer, and the first costs that an individual would face when purchasing recycled vs. conventional paper products. Due to the variety of paper products and the differences in grades and qualities, several assumptions had to be made in order to conduct a financial analysis. Because of minimal data from the industry, research was conducted via a market spot-check, i.e. price comparison, in addition to any published values. Different types of paper were added to proportionally to reflect a more accurate price, and weighted according to the Environmental Paper Network’s published global paper consumption by type (EPN, 2018). Prices differences between virgin (0% to 9% recycled) and recycled (consisting of 30% to 100% recycled materials) were spot-checked on standard office supply and paper sales websites. This spot-check consisted only of US-based websites, due to the price differences globally from international sources and potential shipping costs. In order to achieve continuity across units used in this analysis, the units provided by the supply website were converted to million metric ton of paper and prices were adjusted accordingly. The results of this limited spot-check found that, on average, recycled copy paper costs more than conventional copy paper when purchasing in small amounts (in reams or thousands of sheets). This resulted in an average of 1 metric ton of recycled paper costing on average $219 more than virgin papers.

Operating costs and solution replacement costs were discounted to zero in this research[[2]](#footnote-2). Operating costs, or the ongoing capital, labor, and resources required to produce recycled paper, were discounted down to zero because of agency focus on the business, i.e. consumers purchasing paper, aspect of the financial inputs. The operating costs of producing paper may differ between producing recycled vs. virgin paper, but most paper manufacturers do not provide financial information on the per capita production costs of these two processes and therefore the financial inputs are more clearly depicted where they differ in the market prices to consumers.

Learning rate for the solution technology is assumed to be zero. Data were collected for average prices of waste paper and quantity of waste paper produced in various years, and no significant decrease in price as volume increased could be determined. This is validated by the fact that paper production from both virgin and recycled fibers are mature industries.

## Assumptions

Six overarching assumptions have been made for Project Drawdown models to enable the development and integration of individual model solutions. These are that infrastructure required for solution is available and in-place, policies required are already in-place, no carbon price is modeled, all costs accrue at the level of agency modeled, improvements in technology are not modeled, and that first costs may change according to learning. Full details of core assumptions and methodology will be available at [www.drawdown.org](http://www.drawdown.org). Beyond these core assumptions, there are other important assumptions made for the modeling of this specific solution. These are detailed below.

1. The literature review, especially the life cycle analyses providing carbon emission results of virgin vs. recycled paper, are very specific in that they consider a specific region (Europe, the US, China), a particular paper grade (newsprint, office paper, corrugated cardboard), and particular aspects of the production process (including transportation emissions, or regional mills), and local energy mixes. Approach taken was to find data points that were as comparative as possible in order to absolutely compare conventional (virgin) and recycled paper alternatives. By averaging data in case of numerous sources, results derived can be described as conservative regarding the emission mitigation potential.
2. The effects of woody by-product, also known as black liquor, is currently playing a large role in supplying energy to conventional paper mills. The long-term effects (20-50 years out) of combusting black liquor are unknown at this time, and depending on sources, it may or may not be considered carbon-neutral.
3. Paper production and consumption is projected to increase globally and especially in developing economies for the next 15 years. However, as electronic media is becoming more commonplace (there are nearly 700 million smartphone users in China currently), newsprint may decrease (by 2020 newsprint consumption is predicted to decrease to 7.6 million tons, which is equivalent to the level last experienced in the mid-1960s) (Hetemäki et al. 2002). Office paper and packaging, however, may increase. In this report, the global projection of paper production and recycled paper adoption is increasing, but the market may change rapidly and necessitate a re-evaluation of these results, especially after 2030 and through 2060.
4. Sustainable forest management is a small but growing aspect of the forestry industry. Unfortunately, sustainable forestry and the associated third-party certifications required are voluntary, and exist in certain regions only. Because foreign markets are under less strict standards regarding sourcing and can produce cheaper products, the continued stewardship of forest resources may be undermined. For paper production to continue at its current pace, forests must be managed sustainability or a resource shortage will occur. The materials management aspect of recycled paper is limited without a materials reduction strategy as well, which is beyond the scope of this report.

# Results

## Adoption

Below are shown the world adoptions of the solution in some key years of analysis in functional units and percent for the three Project Drawdown scenarios.

Table 3.1 World Adoption of the Solution

| **Solution** | **Units** | **Base Year (2014)** | **World Adoption by 2050** | |
| --- | --- | --- | --- | --- |
| **PDS1** | **PDS2** |
| Solution Name | *Million Metric Tonnes of Paper Produced from Recycled Fibers* | 154.0 | 541.0 | 589 |
| *(% market)* | 38.11% | 67.26% | 73.28% |

Figure 3‑1 World Annual Adoption 2014-2050

## Climate Impacts

Below are the emissions results of the analysis for each scenario which include total emissions reduction, atmospheric concentration changes, and sequestration where relevant. For a detailed explanation of each result, please see the glossary (Section 6).

Table 3.2 Climate Impacts

| **Scenario** | **Maximum Annual Emissions Reduction** | **Total Emissions Reduction** |
| --- | --- | --- |
| *(Gt CO2-eq/yr.)* | *Gt CO2-eq/yr. (2020-2050)* |
| ***Plausible*** | 0.14 | 2.51 |
| ***Drawdown*** | 0.17 | 3.15 |
| ***Optimum*** | 0.17 | 3.43 |

The solution was integrated with all other Project Drawdown solutions and may have different emissions results from the models. This is due to adjustments caused by interactions among solutions that limit full adoption (such as by feedstock or demand limits) or that limit the full benefit of some solutions (such as reduced individual solution impact when technologies are combined).

Table 3.3 Impacts on Atmospheric Concentrations of CO2-eq

| **Scenario** | **GHG Concentration Change in 2050** | **GHG Concentration Rate of Change in 2050** |
| --- | --- | --- |
| *PPM CO2-eq (2050)* | *PPM CO2-eq change from 2049-2050* |
| **Plausible** | 0.21 | 0.014 |
| **Drawdown** | 0.26 | 0.01 |
| **Optimum** | 0.28 | 0.01 |

Figure 3.2 World AnnualGreenhouse Gas Emissions Reduction

## Financial Impacts

Below are the financial results of the analysis for each scenario. For a detailed explanation of each result, please see the glossary.

Table 3.4 Financial Impacts

| **Scenario** | **Cumulative First Cost** | **Marginal First Cost** | **Net Operating Savings** | **Net Profit Margin** | **Lifetime Profit Margin** | **Lifetime Cashflow Savings NPV (of All Implementation Units)** |
| --- | --- | --- | --- | --- | --- | --- |
| *2015-2050 Billion USD* | *2015-2050 Billion USD* | *2020-2050 Billion USD* | *2020-2050 Billion USD* | *2020-2050 Billion USD* | *Billion USD* |
| **Plausible** | 5,076 | 500.91 | 0 | 0 | 0 | - |
| **Drawdown** | 5,901 | 607.92 | 0 | 0 | 0 | - |
| **Optimum** | 6,362 | 668.45 |  |  |  |  |

# Discussion

Based on the results of the climate mitigation and financial feasibility analyses in the Project Drawdown model, recycled paper has the potential to meaningfully contribute to Drawdown. Recycled paper directly emits on average 0.39 metric tons CO2,eq per metric ton produced less than virgin paper, in addition to indirectly emissions being on average 0.61 metric tons CO2,eq less for recycled paper than virgin paper per metric ton produced. Indirect emissions are largely caused by international and domestic transport associated to paper trade, but also processes associated with cutting down raw materials, timber, and transporting it to paper mills. Furthermore, recycled paper has additional environmental benefits as compared to conventional paper production that are not be accounted for in this report, but are included in other Drawdown solutions, like landfill savings and forest protection.

Recycled paper currently is more expensive to purchase, but technical limitations do not prevent the adoption rate of recycled paper can reach the predicted maximum recycled content of 67-73%. Global paper production and consumption are predicted to rise globally, especially in the emerging paper economies, where paper and packaging is in high demand. However, several developed economies are gradually reducing their paper production and consumption rates. This is due to decreasing stocks of virgin source materials, as well as decreased demand due to the substitution of electronic media, especially in its role of replacing newsprint. The growth of electronic media will play a very important part in the paper industry’s growth or decline in the future. Developing economies, as they become more saturated with electronic media, may in fact not consume nor produce as much paper products as is currently predicted. This will present a difficulty for recycled paper’s adoption rate as it requires a growing paper industry overall. Regardless, recycled paper presents an emissions reduction solution that should be considered at the forefront of achieving climate drawdown as part of a broader array of materials reduction solutions.

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# Glossary

**Adoption Scenario** – the predicted annual adoption over the period 2015 to 2060, which is usually measured in **Functional Units**. A range of scenarios is programmed in the model, but the user may enter her own. Note that the assumption behind most scenarios is one of growth. If for instance a solution is one of reduced heating energy usage due to better insulation, then the solution adoption is translated into an increase in use of insulation. There are two types of adoption scenarios in use: **Reference (REF)** where global adoption remains mostly constant, and **Project Drawdown Scenarios (PDS)** which illustrate high growth of the solution.

**Approximate PPM Equivalent** – the reduction in atmospheric concentration of CO2 (in **PPM**) that is expected to result if the **PDS Scenario** occurs. This assumes a discrete avoided pulse model based on the Bern Carbon Cycle model.

**Average Abatement Cost** – the ratio of the present value of the solution (**Net** **Operating Savings** minus **Marginal First Costs**) and the **Total Emissions Reduction**. This is a single value for each solution for each **PDS Scenario**, and is used to build the characteristic “*Marginal Abatement Cost*” curves when Average Abatement Cost values for each solution are ordered and graphed.

**Average Annual Use** – the average number of functional units that a single implementation unit typically provides in one year. This is usually a weighted average for all users according to the data available. For instance, total number of passenger-km driven by a hybrid vehicle in a year depends on country and typical number of occupants. We take global weighted averages for this input. This is used to estimate the **Replacement Time**.

**Cumulative First Cost** – the total **First Cost** of solution **Implementation Units** purchased in the **PDS Scenario** in the analysis period. The number of solution implementation units that are available to provide emissions reduction during the analysis period is dependent on the units installed prior to the analysis period, and hence all implementation units installed after the base year are included in the cumulative first costing (that is 2015-2050).

**Direct Emissions** – emissions caused by the operation of the solution, which are typically caused over the lifetime of the solution. They should be entered into the model normalized per functional unit.

**Discount Rate**- the interest rate used in discounted cash flow (DCF) analysis to determine the present value of future cash flows. The discount rate in DCF analysis takes into account not just the time value of money, but also the risk or uncertainty of future cash flows; the greater the uncertainty of future cash flows, the higher the discount rate. Most importantly, the greater the discount rate, the more the future savings are devalued (which impacts the financial but not the climate impacts of the solution).

**Emissions** **Factor**– the average normalized emissions resulting from consumption of a unit of electricity across the global grid. Typical units are kg CO2e/kWh.

**First Cost**- the investment cost per **Implementation Unit** which is essentially the full cost of establishing or implementing the solution. This value, measured in 2014$US, is only accurate to the extent that the cost-based analysis is accurate. The financial model assumes that the first cost is made entirely in the first year of establishment and none thereafter (that is, no amortization is included). Thus, both the first cost and operating cost are factored in the financial model for the first year of implementation, all years thereafter simply reflect the operating cost until replacement of the solution at its end of life.

**Functional Unit** – a measurement unit that represents the value, provided to the world, of the function that the solution performs. This depends on the solution. Therefore, LED Lighting provides petalumen-hours of light, Biomass provides tera-watt-hours of electricity and high speed rail provides billions of passenger-km of mobility.

**Grid Emissions** – emissions caused by use of the electricity grid in supplying power to any operation associated with a solution. They should be in the units described below each variable entry cell. Drawdown models assume that the global electric grid, even in a Reference Scenario, is slowly getting cleaner, and that emissions factors fall over time resulting in lower grid emissions for the same electricity demand.

**Implementation Unit** – a measurement unit that represents how the solution practice or technology will be installed/setup and priced. The implementation unit depends on the solution. For instance, implementing electric vehicles (EV) is measured according to the number of actual EV’s in use, and adoption of Onshore Wind power is measured according to the total terawatts (TW) of capacity installed worldwide.

**Indirect Emissions** – emissions caused by the production or delivery or setup or establishment of the solution in a specified area. These are NOT caused by day to day operations or growth over time, but they should be entered into the model normalized on a per functional unit or per implementation unit basis.

**Learning Rate/Learning Curve** - Learning curves (sometimes called experience curves) are used to analyze a well-known and easily observed phenomenon: humans become increasingly efficient with experience. The first time a product is manufactured, or a service provided, costs are high, work is inefficient, quality is marginal, and time is wasted. As experienced is acquired, costs decline, efficiency and quality improve, and waste is reduced. The model has a tool for calculating how costs change due to learning. A 2% learning rate means that the cost of producing a *good* drops by 2% every time total production doubles.

**Lifetime Capacity** – this is the total average functional units that one implementation unit of the solution or conventional technology or practice can provide before replacement is needed. All technologies have an average lifetime usage potential, even considering regular maintenance. This is used to estimate the **Replacement Time**. and has a direct impact on the cost to install/acquire technologies/practices over time. E.g. solar panels generate, on average, a limited amount of electricity (in TWh) per installed capacity (in TW) before a new solar panel must be purchased. Electric vehicles can travel a limited number of passenger kilometers over its lifetime before needing to be replaced.

**Lifetime Operating Savings**–the operating cost in the PDS versus the REF scenarios over the lifetime of the implementation units purchased during the model period regardless of when their useful life ends.

**Lifetime Cashflow NPV**-the present value (PV) of the net cash flows (PDS versus REF) in each year of the model period (2015-2060). The net cash flows include net operating costs and first costs. There are two results in the model: Lifetime Cashflow NPV for a Single **Implementation Unit**, which refers to the installation of one **Implementation Unit**, and Lifetime Cashflow NPV of All Units, which refers to all **Implementation Units** installed in a particular scenario. These calculations are also available using profit inputs instead of operating costs.

**Marginal First Cost** – the difference between the **First Cost** of all units (solution and conventional) installed in the **PDS Scenario** and the **First Cost** of all units installed in the **REF Scenario** during the analysis period. No discounting is performed. The number of solution implementation units that are available to provide emissions reduction during the analysis period is dependent on the units installed prior to the analysis period, and hence all implementation units installed after the base year are included in the cumulative first costing (that is 2015-2050).

**Net Annual Functional Units (NAFU)** – the adoption in the PDS minus the adoption in the REF in each year of analysis. In the model, this represents the additional annual functional demand captured either by the solution in the **PDS Scenario** or the conventional in the **REF Scenario**.

**Net Annual Implementation Units (NAIU)** – the number of **Implementation Units** of the solution that are needed in the PDS to supply the **Net Annual Functional Units (NAFU).** This equals the adoption in the PDS minus the adoption in the REF in each year of analysis divided by the average annual use.

**Net Operating Savings** – The undiscounted difference between the operating cost of all units (solution and conventional) in the **PDS Scenario** minus that of all units in the **REF Scenario**.

**Operating Costs** – the average cost to ensure operation of an activity (conventional or solution) which is measured in 2014$US/**Functional Unit**. This is needed to estimate how much it would cost to achieve the adoption projected when compared to the **REF Case**. Note that this excludes **First Costs** for implementing the solution.

**Payback Period** – the number of years required to pay all the **First Costs** of the solution using **Net Operating Savings**. There are four specific metrics each with one of **Marginal First Costs** or **First Costs** of the solution only combined with either discounted or non-discounted values. All four are in the model. Additionally, the four outputs are calculated using the increased profit estimation instead of **Net Operating Savings**.

**PDS/ Project Drawdown Scenario** – this is the high growth scenario for adoption of the solution

**PPB/ Parts per Billion** – a measure of concentration for atmospheric gases. 10 million PPB = 1%.

**PPM/ Parts per Million** – a measure of concentration for atmospheric gases. 10 thousand PPM = 1%.

**REF/ Reference Scenario** – this is the low growth scenario for adoption of the solution against which all **PDS scenarios** are compared.

**Regrets solution** has a positive impact on overall carbon emissions being therefore considered in some scenarios; however, the social and environmental costs could be harmful and high.

**Replacement Time**- the length of time in years, from installation/acquisition/setup of the solution through usage until a new installation/acquisition/setup is required to replace the earlier one. This is calculated as the ratio of **Lifetime Capacity** and the **Average Annual Use**.

**TAM/ Total Addressable Market** – represents the total potential market of functional demand provided by the technologies and practices under investigation, adjusting for estimated economic and population growth. For this solutions sector, it represents world and regional total addressable markets for electricity generation technologies in which the solutions are considered.

**Total Emissions Reduction** – the sum of grid, fuel, indirect, and other direct emissions reductions over the analysis period. The emissions reduction of each of these is the difference between the emissions that would have resulted in the **REF Scenario** (from both solution and conventional) and the emissions that would result in the **PDS Scenario**. These may also be considered as “emissions avoided” as they may have occurred in the REF Scenario, but not in the PDS Scenario.

**Transition solutions** are considered till better technologies and less impactful are more cost effective and mature.

**TWh/ Terawatt-hour** – A unit of energy equal to 1 billion kilowatt-hours

1. Within the context of this report only. The analysis contained within compared only office paper and did not consider the several other types and qualities of paper and paperboard being produced. [↑](#footnote-ref-1)
2. Operating costs and mill prices of raw materials have been collected and are listed in Variable Meta-Analysis, but are not currently used in any financial calculations in the model. [↑](#footnote-ref-2)