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# Timber market implications of international efforts to reduce emissions from deforestation in developing countries

*A literature review focusing on Europe and other developed regions potentially affected by conservation efforts such as REDD (Reduced Emissions from Deforestation and Forest Degradation)*

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# Summary

Forest-product markets can be affected by policies aimed at mitigating climate change in several ways; directly through substitution of wood products for other materials that yield more greenhouse gas (GHG) and the development and use of bioenergy and biofuel or indirectly through policies involving forest-based carbon sequestration. The most internationally relevant climate mitigation policy with a specific focus on forests, is the United Nations collaborative initiative on Reducing Emissions from Deforestation and forest Degradation (REDD) in developing countries. REDD is an effort to create a financial value for the carbon stored in forests, and thereby provide an incentive for developing countries to reduce emissions from forest loss. In addition to its intended outcomes, forest management strategies and policies such as REDD may have unintentional implications for forest sectors in countries that are not REDD targets, most notably through market linkages. By its very definition, the success of a policy effort like REDD would result in a significant reduction in deforestation and forest degradation, and consequently result in a reduction in timber supply within participating developing countries. Reduced supplies of timber from protected areas may result in increased pressure in other areas to further exploit their forest resources. This relates directly to the issue of negative leakage, i.e., the displacement of deforestation or forest degradation from protected sites to other locations.

This report is part of a study within Future Forests which assesses the potential timber market implications for European nations which source wood products from tropical developing countries affected by REDD related conservation efforts. The report is based on a literature review. The objective is to use the available literature to discern whether there are likely to be timber market implications for European nations which source wood products from tropical developing countries affected by conservation efforts like, e.g., REDD. This objective is closely linked to the issue of negative transnational leakage from conservation projects in the sense of reduced supplies of timber from protected areas exerting pressure on other areas to further exploit their forest resources.

The review is not strictly confined to emission displacements from carbon sequestration projects, since the potential impacts on the exploitation of forest resources outside project areas should be the same, irrespective of the motive for changes in land-use practices. Hence, both studies estimating product leakage, i.e., displacement of wood products resulting from conservation efforts in one location, and carbon leakage, i.e., carbon emissions displacement associated with this product movement, are considered.

There are two principle mechanisms driving leakage. Primary leakage, a type of leakage also referred to as activity shifting, concerns direct leakage effects caused by displacement of baseline activities or agents from one area to the next, e.g., a conservation project leading to displacement of people and deforestation to adjacent areas. Secondary leakage, often referred to as market effects leakage, occurs when policy actions in one place indirectly create incentives for third parties to increase emissions elsewhere. Market effects leakage is caused by a shift in market equilibrium, e.g., forest-conservation projects reducing local timber supply and thus increasing prices and pressures on forest outside the project area.

The leakage type is linked to the geographical scale. Activity shifting leakage is typically a localized process, when smallholders or local communities are affected in subsistence activities such as small-scale agriculture or firewood collection. However, when deforestation agents are internationally operating logging or agribusiness companies, primary leakage can also occur on an international level. Market effects leakage is most likely to occur on national and international scale. All of the reviewed papers concern market effects and reflect the geographical scope, mostly being transnational as well as the drivers of leakage i.e., the production of agricultural and/or timber.

Market leakage can be difficult to account for due to the rapid nature of market adjustments, and more generally due to the difficulty of identifying cause and effect. International leakage is particularly hard to quantify, as it is difficult to accurately attribute increasing emissions (or deforestation) in one country to emissions regulation (or forest conservation) in another country.

However, there are two basic approaches to estimate market leakage: (i) modeling and (ii) an analytic approach, using theoretical reasoning only.

Nine of the ten studies reviewed estimate market leakage by means of modeling, and of these, seven considered transnational leakage. The results of these studies show varying degrees of market leakage. The two studies that estimate leakage *ex post* provide strong empirical evidence that efforts to reduce logging in one place do tend to shift harvests elsewhere. Wood products in the studies reviewed are in general dealt with on a quite aggregated scale. Related to this, wood-products in protected sites (within project boundaries) and in the locations where leakage take place are at least implicitly assumed to be more or less perfect substitutes. The plausibility of this assumption depends on the geographical scale. The assumption of perfect substitution among wood products appears more reasonable when the scope is national, regional and continental, than when it is global. Hence, the degree of leakage could be exaggerated in some of the modeling studies having a global scope. This is because leakage diminishes if the timber supplied from non-reserved forests is a poor demand substitute for the timber retained in reserved forests.

Two of the studies deal explicitly with product leakage from tropical countries/regions. Ex ante simulations in a study with global scope indicate considerable leakage from cooperation in forest conservation among tropical forest regions alone. However, here again wood are dealt with on a quite aggregated scale. Ex post estimations of products displacement/leakage from forest conservation in individual tropical developing countries also indicate considerable leakage. Though wood products here are on a quite disaggregated level, the fact that displacement is estimated through net-imports of wood products implies perfect substitutability between reserved and non-reserved timber, which could lead to an overestimation of leakage. However, in this instance most of the imported wood came from other developing countries, making the assumption of perfect substitution more reasonable. The estimate of leakage fails to recognize that displaced/leaked wood production may be traded to third countries, thus potentially underestimating product leakage.

All in all, the literature suggests that conservation efforts like REDD could result in increased utilization of forest resources in other world regions such as Europe. Hence, should REDD prove successful it would likely result in at least a temporary reduction in tropical hardwood timber supply, thereby reinforcing the current trend of declining market share for tropical timber. Should the REDD-affected countries have a collectively small impact in the global timber market, the avoided deforestation actions would be especially prone to leakage, since the supply contraction could be easily replaced by increased supply elsewhere. This leakage, small in absolute terms, would be particularly difficult to identify. Thus, a comprehensive analysis of potential impacts on wood-product markets in importing regions like Europe should apparently encompass a thorough mapping of the trends in the end-uses of tropical timber.

# Content

# 1. Introduction

## 1.1 Background

Policies aimed at mitigating climate change can affect forest-product markets in various ways: directly by (i) promoting substitution, i.e., by encouraging the use of wood products instead of other materials that yield more greenhouse gas (GHG) emissions during the course of their production, subsequent use and disposal (Binkley & van Kooten, 1994) and by (ii) influencing the development and use of bio-energy and bio-fuel, e.g., the European Union renewable energy sources (RES) directive (European Commission, 2008); and indirectly via (iii) forest-based carbon sequestration efforts such as the United Nations collaborative initiative on Reducing Emissions from Deforestation and forest Degradation (REDD) in developing countries (UN-REDD, 2009a).

REDD is an effort to create a financial value for the carbon stored in forests, providing incentives for developing countries to reduce emissions from forests (Holmgren, 2010; UN-REDD, 2009b). REDD primarily refers to: (i) developing mechanisms to make payments to developing countries for reducing emissions from deforestation and forest degradation (compared with a reference level); and (ii) readiness activities, i.e., capacity building and other preparatory and demonstration activities, which prepare countries to participate in the REDD mechanism (Angelsen & Wertz-Kanounnikoff, 2008).

In addition to the potential for reducing atmospheric carbon-dioxide ($CO_2$), forests provide a number of benefits such as timber, fuelwood, food, shelter, watershed services, biodiversity, recreation, and aesthetics, and medical plants (Pearce, 2001; Murray *et al*., 2004). Hence land-use change and forestry are seen as mitigation options with potentially low opportunity costs and high ancillary benefits (see, e.g., IPCC, 2000).

Increasing the global total of standing forest biomass increases the sequestration of atmospheric carbon. This can be achieved by converting non-forest land into forests, i.e., by afforestation, reducing deforestation, and/or by appropriate adjustment of forest management and silvicultural regimes. Management activities promoting increased growth and volume will typically enhance carbon sequestration (see, e.g., Sedjo *et al*., 1995). Further, reducing and/or delaying harvests (i.e., lengthening rotations) increases the amount of carbon sequestered (Hoen & Solberg, 1994; van Kooten *et al*., 1995; Backéus *et al*., 2005).

Reducing tropical deforestation is perhaps the most efficient approach for carbon sequestration. Tropical forests are prominent sources of exchange of $CO_2$ between the land and the atmosphere, constituting the largest terrestrial carbon sink, while tropical deforestation corresponds to around forty percent of the global fossil fuel carbon emissions (Pan *et al*., 2011). The causes of deforestation vary from country to country (UN-REDD, 2008). Logging is one of the main drivers of deforestation worldwide in the tropics (see, e.g., Geist & Lambin, 2001; Sohngen & Brown, 2004), often combined with conversion to agriculture or grazing (Rowe *et al*., 1992).

However, forest management strategies and policies targeted at developing countries, such as REDD, may have unintentional implications for the forest sector in countries that are not targeted. By its very definition, the success of a policy effort like REDD would result in a significant reduction in deforestation and forest degradation, and consequently result in a reduction in established timber supplies within participating developing countries.

Reduced supply of timber from a REDD participating region may result in the increased exploitation of forest resources elsewhere (Martello *et al*., 2010). Hence, reducing logging in one location often just shifts it to another (Gan & McCarl, 2007). Such an outcome is indicative of *negative leakage*, i.e., the indirect (and unintentional) impact that a targeted land-use, land-use change and forestry activity (LULUCF) in a certain location at a certain time has on carbon storage at another place or time (IPCC, 2000; Ghazoul *et al*., 2010). Or, put in another way, the loss of carbon, primarily as woody biomass, outside of the system boundary or project areas due to changes in land-use practices resulting from activities within project areas (see, e.g., Roshetko *et al*., 2007; McKinley *et al*., 2011; Ghazoul *et al*., 2010). Policies that aim to reduce GHG emissions through avoided deforestation and reduced forest degradation could affect global forestry activity, should they lead to a significant reduction in timber supply and thus result in price increases which would in turn induce a supply response outside project boundaries (Sohngen & Brown, 2004; Murray, 2008). This mechanism is referred to as *market effects* leakage (see IPCC, 2000).

Hence, an important question concerns the spatial scale of REDD, i.e., whether accounting and crediting should take place at sub-national (or project) level, at national level, or at both levels in a nested approach (Angelsen *et al*., 2008). National-level carbon and forest accounting-as suggested by the Copenhagen Accord (UNFCCC, 2010)-neutralizes the net effects of leakage within national boundaries, but cannot account for cross-border leakage (Laurance, 2007). A sub-national or project approach which allows easier participation for countries with weak governance, is attractive to private investors, and enables early involvement and wide participation. This approach may, however, suffer from domestic leakage and is unable to address the broader forces driving deforestation and forest degradation (Angelsen *et al*., 2008).

## 1.2 Objective and delimitations

The current report is part of a sub-study within the Future Forests component project *Preferences and demand for forest goods and services and their relevance for silvicultural practices* addressing implications for developed countries, such as Sweden from reducing established wood production from developing countries.

The report is based on a literature review. The objective is to use the available literature to discern whether conservation efforts, like REDD, in tropical developing countries are likely to result in timber market implications in European nations. This objective is closely linked to the issue of negative transnational leakage from conservation projects in the sense of reduced supplies of timber from protected areas exerting pressure on other areas to further exploit their forest resources. Positive leakage, also referred to as spillover, i.e., positive externalities of projects through the motivation of emission savings outside the accounting boundary (Henders & Ostwald, 2012), are not dealt with in this paper.

Further, the review is not strictly confined to emission displacements from carbon sequestration projects, since the potential impacts on the exploitation of forest resources outside project areas should be the same, irrespective of the motive for changes in land-use practices. Hence, both studies estimating *product leakage*, i.e., displacement of wood products resulting from conservation efforts in one location, and *carbon leakage*, i.e., carbon emissions displacement associated with this product movement, (see Murray, 2008) are considered.

## 1.3 Definitions of terms used

Throughout this paper, the term wood products is used in the meaning of commodities made from woody biomass, including all of the primary wood products manufactured in the forest processing sector (sawnwood, wood-based panels, paper and paperboard) and the main inputs or partly processed products used in the sector (roundwood and wood pulp). Further, the term conservation, the same as in the literature reviewed, is used in a generic sense encompassing forest preservation set-asides or avoided deforestation projects.

# 2. Methodology

The review began with a literature search of the search databases Web of Knowledge, ScienceDirect and Scopus. These databases cover a wide range of literature sources, specifically scientific journals, and provide mechanisms to filter out peer reviewed from grey literature and to expand or restrict the search scope, e.g. through specifying the subject area, the use of Boolean operators and possibilities to search in the full text or only in parts of an article. This is the case especially with ScienceDirect database. The literature search and analysis was conducted between November 2011 and March 2012.

As already pointed out, the overall objective of this literature review is intimately linked to the issue of land-use leakage. Hence, to generate articles relevant to this objective, the keywords /search terms carbon, forest, wood, timber and leakage were used. These key words are assumed to sufficiently generate articles that cover our topic. These search terms were trial-searched repeatedly for all databases to determine which Boolean operators, sequence of search strings, and aspect of the article to focus on (e.g. title, abstract, etc.), to ensure a sufficiently encompassing assessment of the available literature. The following search-term sequence was used: carbon AND forest AND wood OR timber, with a subsequent search within these results for "leakage".

The search was then limited to the title, abstract and keywords for two main reasons. First, it was found from the trial-search that searching in the whole document/article retrieves most, if not all, of the available literature containing such search-terms in a database even where a search-term is found only in the reference list, and second, it was assumed that an abstract reflects and provides a comprehensive and precise overview and content of an article.

The database search included all articles published since (default) 1822, 1910 and 1960 for ScienceDirect, Web of Knowledge and Scopus databases respectively. It also included a search of all document types (e.g. articles, reviews, conference papers/articles, editorial, in press, in journals, in books, etc.) and all subject areas (e.g. agricultural & biological (life) sciences, environmental sciences, economics & finances, social sciences & humanities, health sciences, etc.). This search retrieved one hundred and fifteen articles (Figure 1), of which twenty-seven were found to be overlapping, but only three papers are common to all databases.

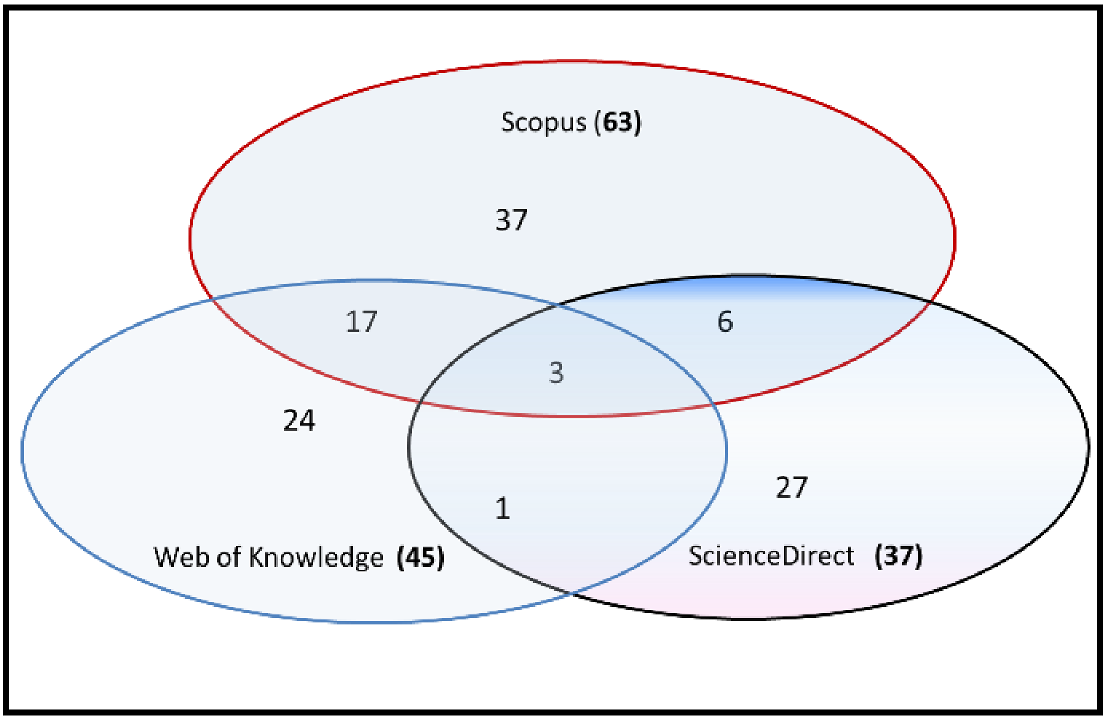


Figure 1. Database search results

Since this paper is concerned with leakage from conservation efforts such as REDD, the studies found in the first literature search were then screened (second search) for articles dealing with leakage from conservation projects. The assessment of whether or not articles were of relevance was mainly based on screening the abstracts. This second search resulted in six articles, which were found among the overlap between Scopus and Web of Knowledge(five papers) and Web of Knowledge and Science Direct (one paper) respectively. Further, four articles were found among papers referenced in the articles generated from the second search.

# 3. Literature review results

## 3.1 Leakage types

There are two principle mechanisms driving leakage (IPCC, 2000). Primary leakage, also referred to as *activity shifting*, concerns direct leakage effects caused by displacement of baseline activities or agents from one area to the next (Aukland *et al*., 2003), e.g., a conservation project leading to displacement of people and deforestation to adjacent areas (IPCC, 2000). Secondary leakage, often referred to as *market effects* (Schwarze *et al*., 2002), occurs when policy actions in one place indirectly creates incentives for third parties to increase emissions elsewhere (Aukland *et al*., 2003). Market effects leakage is caused by a shift in market equilibrium, e.g., forest-conservation projects reducing local timber supply and thus increasing prices and pressures on forest outside the project area (Sohngen *et al*., 1999; Schwarze *et al*., 2002). Thus, under a REDD mechanism, a continued international demand for internationally traded commodities could lead to higher prices when meeting a reduced production in REDD countries; incentivizing production elsewhere and thus creating leakage (Skutsch & McCall, 2010).

The leakage type is linked to the geographical scale. Activity shifting leakage is typically a localized process, when smallholders or local communities are affected in subsistence activities such as small-scale agriculture or firewood collection (Schwarze *et al*., 2002; Henders & Ostwald, 2012). However, when deforestation agents are internationally operating logging or agribusiness companies, primary leakage can also occur on an international level. Market effects leakage is most likely to occur on national and international scale (Ibid.). All of the reviewed papers assessing leakage from forest conservation concern market effects. This reflects the drivers of leakage in the studies in question, i.e., the production of agricultural and/or timber commodities (see, e.g., Henders & Ostwald, 2012) as well as the geographical scope, which is mostly transnational (see Table 1).

Table 1. Papers estimating leakage.

| **Modeling** | | | | | |
|---|---|---|---|---|---|
| **Study id** | **Estimation approach** | **Drivers** | **Geographical leakage scale** | **Leakage magnitude*** | **Type of product(s)** |
| 1 | Ex ante | Timber markets | global | Overall (all sectors) leakage of 28%, reduced by 0.01-0.02% with the inclusion of forestry mitigation. | “timber” |
| 2 | Ex ante | Overall markets | global | Overall leakage 45%, 12% with REDD credits | n.s. |
| 3 | Ex ante | Timber markets | global | Around 50% on average | n.s. |
| 4 | Ex ante | Timber & agricultural markets | regional USA | Logging set-aside: 16% (set-aside in Pacific-northwest) -68% (set-aside in South-central) | "timber" |
| 5 | Ex ante | Timber markets | global | 42% (Canada) –95% (Russia) | lumber and wood products sector, pulp and paper sector |
| 6 | Ex ante | Timber markets | national | 2% (elastic demand) - 38% (inelastic demand) | "Boards" |
| 7 | Ex ante | Timber markets | global | 5% in area terms | "timber logs" (industrial round wood) |
| 8 | Ex post | Timber & agricultural markets | global | 22% for wood and agricultural products combined; 74% considering wood products only | raw, primary & secondary-wood products |
| 9 | Ex post | Timber markets | (N America) | Total (Continental) 84%, transnational (to Canada) 26% | softwood lumber |

| **Analytical approach** | | | | |
|---|---|---|---|---|
| **Study id** | **Drivers** | **Geographical leakage scale** | **Leakage magnitude** | **Type of product(s)** |
| 4 | Timber & agricultural markets | transnational | 47%, assuming unitary elasticities of supply (1.0) and demand (−1.0) | “timber” |
| 5 | Timber markets | transnational | n.s. | “timber” |

| | | | | |
|---|---|---|---|---|
| 10 | Timber markets | global | from 0 to over 100% | n.s. |

Note: n.s. = not specified. The studies referred to in Table 1 are labeled as follows: 1. Michetti & Rosa (2012); 2. Bosello *et al*., (2010); 3. Sun & Sohngen (2009); 4. Murray *et al*. (2004); 5. Gan & McCarl (2007); 6. Sohngen & Brown (2004); 7. Sohngen *et al*. (1999); 8. Meyfroidt *et al*. (2010); 9. Wear & Murray (2004); 10. Magnani *et al*. (2009). (Magnani, Dewar, & Borghetti, 2009). *Leakage magnitude is estimated as the ratio of increased activity outside the project area (carbon emissions, harvesting and timber production) and decreased activity within the project area

## 3.2 Estimating market leakage

In general, market leakage can be difficult to account for due to the rapid nature of market adjustments (McKinley *et al*., 2011), and more generally due to the difficulty of identifying cause and effect (Murray *et al*. 2004). International leakage is particularly hard to quantify, as it is difficult to accurately attribute increasing emissions (or deforestation) in one country to emissions regulation (or forest conservation) in another country (Skutsch *et al.*, 2007). Hence, as leakage is not directly observable, it must be estimated (Murray, 2008). There are two basic approaches to estimate market leakage: (i) modeling and (ii) an analytic approach, using theoretical reasoning only.

### *3.2.1 Modeling*

The studies in Table 1 are divided between those that estimate leakage by modeling (i) before the fact (*ex ante*) using predictive simulation and (ii) after the fact (*ex post*) using observed market data (see also Murray, 2008).

The study by Michetti & Rosa (2012) belongs to the first group. They use general equilibrium modeling to analyze the role of forest-based carbon sequestration in a unilateral emission reduction policy by twenty-seven EU member countries (EU27). Though the study focuses on carbon leakage from overall economic activity−presenting results that carbon leakage could be alleviated with the inclusion of forest-based carbon sequestration−the study also provides an assessment of product leakage. Their results suggest that decreased timber supply in the short-run, as a result of higher rotation periods in EU27, would be followed by markedly increasing prices and significantly higher roundwood production in other world regions.

In the same context as Michetti & Rosa (2012), Bosello *et al*. (2010) also apply a general equilibrium model. They estimate carbon leakage from overall economic activity, i.e., account for both direct and indirect effects occurring on land, crops' and timber markets resulting from lower deforestation rates. Their results imply that the possibility for the EU to buy emission reductions from REDD countries reduces leakage as non EU emissions are significantly reduced compared with a unilateral approach. This is a result of this approach being much less penalizing in terms of competitiveness than a unilateral emission reduction by the EU27. Further, timber prices in the region selling REDD credits (i.e., Sub Saharan Africa, Central and South America, and Southeast Asia)−through a contraction in supply−increase compared to the business-as-usual scenario.

Sun & Sohngen (2009) also apply *ex ante* modeling. Using a global land use and forestry model, they examine the potential role of forest set-asides in global carbon sequestration. The results indicate that policies focusing exclusively on set-asides invite large carbon leakages from harvesting and land-use change activities onto lands that are not protected by the set-aside policy. Crediting all deviations from the baseline, including sequestration on forest land where timber harvests occur, generates the largest carbon gain (Ibid.).

Murray *et al*. (2004) use a forest and agricultural sector optimization model to assess carbon leakage from logging set-asides *ex ante*. The study looks at policies that would be implemented unilaterally by regions within the U.S. to examine how leakage fundamentals might vary by region. As actual policy implementation would likely not be confined to individual regions, but would be national or international in coverage, the leakage estimates from the study might be seen as high end estimates relative to a national or international program (Murray, 2008). The regional estimates range from quite low (16 %) to quite high (64 %).

Gan & McCarl (2007) use general equilibrium modeling to estimate the magnitude of product leakage at a global level *ex ante*. Their simulation results indicate that a significant proportion of reduced timber harvesting implemented in a country or region can "leak" to elsewhere. Regional cooperation reduces total displacement, though not as much as one might expect. Of particular interest in this context is the finding that cooperation in forest conservation only among tropical forest regions alone results in 78% leakage to other world regions. Further, the authors note that the relative insensitiveness of leakage to changes in the degree of substitutability shown in the simulations could be seen as partially supporting the assumption of perfect substitution among wood products originating in different countries or regions. This assumption enjoys some support in actual trade patterns, showing that temperate hardwoods are substituting for tropical hardwoods in Europe (UN, 2011). Hence, temperate (especially oak) supplying countries have increased their share of the European sawn hardwood market, at the expense of tropical countries (Ibid.).

Sohngen & Brown (2004) develop methods for estimating leakage from forest-based carbon projects that seek to reduce carbon emissions from timber harvesting in tropical forests. A dynamic optimization model of timber markets is used to estimate carbon leakage from a logging ban and ensuing shifting harvests in Bolivia, *ex ante*. The authors note that demand elasticity and wood decomposition rates have the largest effects on carbon leakage estimates. Leakage is lowest when demand is more elastic and wood decomposition rates are faster, and vice-versa when these conditions are reversed.

Developing a global timber market model, Sohngen *et al*. (1999) estimate *ex ante* the impacts of setting aside forestland in both North America and Europe. Product leakage is expressed in terms of the land area necessary to produce the timber forfeited in the conservation area. The authors conclude that larger-scale conservation efforts could make timber scarce, increasing prices, and leading to increased harvesting in other areas. The results indicate that approximately one hectare of previously inaccessible land in other parts of the world is lost for every twenty hectares conserved in North America and Europe.

Meyfroidt *et al*. (2010) examine *ex post* whether shifts from net deforestation to net reforestation in a number of developing countries (Bhutan, Chile, China, Costa Rica, El Salvador, India, and Vietnam) involved a geographic displacement of forest clearing across countries through trade in agricultural and wood products. Historical trade data are analyzed in order to estimate product leakage, similarly to Sohngen *et al*. (1999) expressed in terms of the land area necessary to produce net-imports of forest and/or agricultural products in the producing country. The results indicate noticeable combined displacement/leakage and quite high for wood products alone.

Wear & Murray (2004) also estimate product leakage *ex post*. The authors use econometric modeling of observed market data to simulate the effects of reductions in federal timber sales in The Pacific Northwester of USA. Their study estimates that forty-three percent of the foregone harvests on public lands in the Pacific Northwest were shifted to private lands within the region, another fifteen percent were shifted to other regions in the USA. In addition, twenty-six percent of foregone harvests were shifted to Canada, resulting in a total leakage of 84 percent.

### 3.2.2 Analytical approach

A theoretical reasoning which builds on supply and demand functions has in many cases been used to develop a rough estimate of leakage potential. Murray *et al*. (2004) used such an approach to show that carbon leakage is aggravated the more price elastic the timber supply and the less price elastic timber demand. That is, leakage worsen the more responsive supply is to changes in price and the more inclined the market to seek supplies from any sources willing to supply it rather than cut consumption or switch to other commodities in response to price increases. Further, when reserved and non-reserved timbers are not perfect substitutes—reserved forests may contain unique species or qualities of timber that do not have close substitutes outside the reserved area—leakage worsens with the degree of substitutability. Murray *et al*. (2004) also show that when the avoided deforestation actions of the covered countries have a collectively small impact in the global market, the supply contraction is easily replaced by increased supply elsewhere, i.e., there is considerable leakage. Leakage dissipates the larger the share of the world market that is covered by deforestation avoidance policies.

Gan & McCarl (2007) develop an analytical framework for measuring product leakage of forest conservation. They note, in conformity with Murray *et al*. (2004), that the magnitude of product leakage depends on price elasticity of supply and demand. Further, also in accordance with Murray *et al*. (2004), Gan & McCarl (2007) show that the magnitude of leakage depends on the degree of cooperation in conservation among countries. This theoretical result indicates that partial cooperation alone, i.e., when covered countries have a collectively limited impact in the global market, may not lead to a significant reduction of leakage.

Magnani *et al*. (2009) use a simple theoretical model of carbon storage in managed forest ecosystems and their wood products to derive approximate analytical expressions for the carbon leakage induced by decreasing the harvesting frequency of existing forests. The analysis assumes two areas consisting of established medium-growth ('temperate') and slow-growth ('boreal') forest respectively and that a fixed global demand for timber is satisfied. The authors show that reduced harvesting in medium-growth forests, and ensuing increased harvesting intensity in slower-growing forests, induces total leakage in excess of one hundred percent. Global carbon storage is maximized by actively managing medium-growth forests for timber production and protecting slow-growth forests instead (Ibid.).

# 4. Discussion and Conclusions

Nine of the ten studies reviewed estimate market leakage by means of modeling, and of these, seven considered transnational leakage. The results of these studies show varying degrees of market leakage. Wear & Murray (2004) estimate product leakage *ex post*, and provide strong empirical evidence that efforts to stop logging in one place do tend to shift harvests elsewhere.

As is apparent from Table 1, wood products in the studies reviewed are in general dealt with on a quite aggregated scale. Related to this, wood-products in protected sites (within project boundaries) and in the locations where leakage take place are at least implicitly assumed to be more or less perfect substitutes. The plausibility of this assumption depends on the geographical scale. The assumption of perfect substitution among wood products appears more reasonable when the scope is national (Sohngen & Brown, 2004), regional (Murray *et al*., 2004) and continental (Wear and Murray, 2004), than when it is global. Hence, the degree of leakage could be exaggerated in some of the modeling studies having a global scope, as leakage diminishes if the timber supplied from non-reserved forests is a poor demand substitute for the timber retained in reserved forests, as shown by Murray *et al*. (2004). In this context it is worth noting that current trade patterns – temperate hardwoods are substituting for tropical hardwoods in Europe – provide some support for the assumption of perfect substitution among wood products originating in different countries or regions.

Two of the studies deal explicitly with product leakage from tropical countries/regions. The simulations in Gan & McCarl (2007) indicate considerable leakage from cooperation in forest conservation among tropical forest regions alone, echoing the analytically derived conclusion that partial cooperation may not lead to a significant reduction of leakage (see Murray *et al*., 2004; Gan & McCarl, 2007). The *ex post* estimations in Meyfroidt *et al*. (2010), also indicate high products displacement/leakage from forest conservation in individual tropical developing countries. The fact that displacement is estimated through net-imports of wood products implies perfect substitutability between reserved and non-reserved timber, which could lead to an overestimation of leakage. However, Meyfroidt *et al*. (2010) note that most of the imported wood came from other developing countries, making the assumption of perfect substitution more reasonable. Further, as illegal trade is not recorded in the trade databases used; net displacements/leakage is underestimated for countries importing illegally traded timber and overestimated for countries sourcing illegally timber (Meyfroidt *et al*., 2010). The estimate of

leakage in Meyfroidt *et al*. (2010) also fails to recognize that displaced/leaked wood production may be traded to third countries, thus potentially underestimating product leakage.
All in all, the literature – though differing as to the magnitude – suggests that conservation efforts in tropical developing countries could result in increased utilization of forest resources in other world regions such as Europe. Hence, should REDD prove successful it would likely result in at least a temporary reduction in tropical hardwood timber supply, thereby reinforcing the current trend of declining market share for tropical timber. Should the covered countries have a collectively small impact in the global timber market, which is quite likely, at least in the initial stages of REDD, the avoided deforestation actions would be especially prone to leakage, since the supply contraction could be easily replaced by increased supply elsewhere, as shown analytically. This leakage, small in absolute terms, would be particularly difficult to identify. Thus, a comprehensive analysis of potential impacts on wood-product markets in importing regions like Europe should apparently encompass a thorough mapping of trends in the end-uses of tropical timber.

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