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# Carbon footprint as an environmental sustainability indicator for the particleboard produced in Pakistan

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ABSTRACT

This study quantified the carbon footprint of particleboard production in Pakistan using a cradle-to-gate life cycle assessment approach. The system boundary comprised raw materials acquisition, transport, particleboard manufacture and finished product distribution. Primary data were collected through surveys and meetings with particleboard manufacturers. Secondary data were taken from the literature. Greenhouse gas emissions from off-site industrial operations of the particleboard industry represented 52% of the total emissions from the production of 1.0 $m^3$ of particleboard in Pakistan. The on-site industrial operations cause direct greenhouse gas emissions and accounted for 48% of the total emissions. These operations included energy consumption in stationary sources, the company-owned vehicle fleet, and the distribution and marketing of the finished product. The use of natural gas combustion in the stationary and mobile sources, raw material transport and urea-formaldehyde resin production chain accounted for the highest emissions from the particleboard production chain in Pakistan. The identification of the major hotspots in the particleboard production chain can assist the wood panel industry to improve their environmental profile. More efforts are needed to investigate the urea-formaldehyde resin production chain and substitution of roundwood with wood and agri-residues to assess the potential improvements. In addition, renewable energy sources should be encouraged to avoid greenhouse gas emissions by substituting fossil energy. This study also provides a benchmark for future research work to formulate comprehensive greenhouse gas emissions reduction plans, because no previous research work is available on the carbon footprint of particleboard production in Pakistan.

## 1. Introduction

Environmental sustainability has arisen as an important subject amongst the public, researchers, policymakers, and industry. Environmental impacts can be evaluated through various impact-specific indicators based on a life cycle assessment (LCA) approach (Cucek et al., 2012). LCA is a holistic, structured, and internationally standardized tool (ISO, 2006a, 2006b, 2006c, 2006d) for measuring emissions, resource use, environmental and health impacts related to processes or products over their life cycles. The life cycle stages considered may include resource extraction ("cradle") through materials production and manufacturing ("gate"), usage, recovery, recycling, and disposal ("grave") (Guinee et al. (2002); EC, 2010). A footprint is a quantitative measurement describing the appropriation of natural resources by humans (Hoekstra, 2008). The major categories of footprints developed to date are carbon, ecological, and water footprints, forming the so called "footprint family" (Galli et al., 2011, 2012). The carbon footprint was most probably derived from the global warming potential (GWP), an indicator often reported in LCA studies, and was first defined in the scientific literature by Hogevold (2003). Carbon footprint is the sum of all the GHG emissions directly or indirectly caused by a company, organization, process, product or person, usually measured in terms of tonnes or kilograms carbon dioxide equivalents ($CO_2e$) (Lynas, 2007; Wiedmann and Minx, 2007; Hussain et al., 2014). It comprises carbon dioxide, methane, nitrous oxide and fluorinated gas emissions based on 100 years of radiative forcing potential (IPCC, 2007). Carbon footprint is being applied for many reasons, i.e. communication of carbon footprint to customers, to help develop GHG reduction strategies along the product life cycle, and to assist consumers to identify products that contribute less to climate change (Bolwig and Gibbon, 2009).

Carbon footprint reporting or disclosure to the third party or public can be part of compliance with the legislative requirements, carbon trading, improvement of brand image or as a part of corporate social

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responsibility (Pandey et al., 2011; L.E.K. Consulting LLP, 2007; Carbon Trust, 2007b). Legislative measures have been taken to calculate and diminish the carbon footprint of organizations, cities and products and thus is becoming a common component of policy development (Courchene and Allan, 2008; Good Company, 2008). Some corporations have recognized that a carbon constrained economy may arrive soon and therefore are moving to quantify their carbon footprint and to reduce emissions (Kleiner, 2007).

Recently, numerous methodological approaches have been developed to calculate products' carbon footprints (Garcia and Freire, 2014), for example the GHG Protocol Product Standard (WRI and WBCSD, 2011); the PAS 2050 (BSI, 2011); ISO/TS 14067 (ISO/TS, 2013) and the Climate Declaration (IEC, 2008a). The ISO/TS 14067 published a carbon footprint tool (ISO/TS, 2013) which provides specific requirements and guidelines for the calculation and communication of the carbon footprint of products, building on existing ISO standards on life cycle assessment (ISO, 2006a, 2006b, 2006c, 2006d) and on standards for environmental labels and declarations (ISO, 2000, 2006a, 2006b, 2006c, 2006d). This standard provides requirements for the treatment of GHG emissions and removals e.g. fossil and biogenic carbon, carbon storage in products, land-use change and additional requirements for the communication of the carbon footprint.

Wood based products have multiple environmental benefits as compared with non-wood products (Lippke et al., 2011; Ritter et al., 2011; Eriksson et al., 2012; Bergman et al., 2014), for example wood based products are made from renewable materials and store carbon. They are manufactured using wood residues bonded with synthetic adhesive binders under high heat and pressure (ANSI, 2009; Kouchaki-Penchah et al., 2016), and their properties are adjusted per their intended usage such as structural cladding in building or non-structural use in furniture (Wilson, 2010a; Puettmann et al., 2013). Pakistan is a growing manufacturer and consumer of wood-based panels, specifically plywood, fiberboard and particleboard (SEMDA, 2006). The particleboard industry uses mostly poplar, eucalyptus, farash, sumbal and mango trees as raw materials. Currently, there are more than 20 particleboard mills in Pakistan (EC-FAO Partnership Programme, 2002). Particleboard is consumed internally in Pakistan and is exported to Afghanistan, Sri Lanka, Saudi Arabia and other Gulf states in the form of furniture. The particleboard industry contributed 8.4% to the GDP (gross domestic product) of the country in 2004–2005 (ww.boi.gov.pk).

In the past, shisham, chir, oak, teak and kikar woods and bamboo were used in the Pakistani furniture industry but now particleboard is widely used. The furniture industry consumes about 60% of the particleboard production. The population growth rate and a shortfall in supply of 6 million houses in the country suggest that demand for particleboard in Pakistan will remain strong. Pakistan is forest-poor country with a total area of 4.2 million hectares under forests, which makes about 4.8% of the total land area of the country. Pakistan has also only 0.05 ha of forest per capita as compared to the world average per capita of 1.0 ha. The continuous increase in the population is also escalating forest depletion, because of dependence on forests for fuelwood, house construction and furniture. About 2.35 million $m^3$ of industrial roundwood was harvested from the state-owned forests and farmlands from 1996 to 2000. However, due to deficiency of roundwood in the country and more demands by the construction and forestry sector, about 532,000 $m^3$ of roundwood are imported each year to fulfill the country's roundwood demands. Forests also provided fuelwood which provides 32% of the country's energy needs. About 60% of the urban and 90% of the rural households consume fuelwood for primary energy needs such as cooking and heating (PDRRFF, 2000; Tahir et al., 2010).

According to a recent report of the Intergovernmental Panel on Climate Change (IPCC), the global industrial sector contributed about 30% of the total GHG emissions (IPCC, 2014; Kucukvar et al., 2015). Thus, sustainable and environment friendly manufacturing facilities are crucial for realizing a low-carbon economy (Wang et al., 2013; Hoffmann and Busch, 2008). A variety of forest based products have been investigated in carbon footprint studies, ranging from biofuels (e.g., see Cherubini et al., 2009) to materials consumed in home construction (e.g., see Salazar and Sowlati, 2008; Perez-Garcia et al., 2005; Gustavsson and Sathre, 2006). Similarly, some forest products corporations have also been calculating their own carbon footprints (e.g., see Miner, 2010 and Heath et al., 2010); however, few of these studies are published in peer reviewed journals (Parigiani et al., 2011). Often, wood is assumed to be a carbon-neutral material as it embodies biogenic carbon (England et al., 2013) that was recently sequestered by the living tree. However, wood processing operations (such as primary and secondary raw materials acquisition and the manufacturing processes of particleboard) also consume fossil fuels that contribute to the carbon footprint (Werner and Richter, 2007). This study evaluates the total GHG emissions from raw material extraction and transport, manufacturing of particleboard product, fossil fuels and purchased electricity consumption and the transportation of finished particleboard product to markets in Pakistan. This study provides a benchmark for future research work to formulate comprehensive GHG emissions reduction plans, because no previous data are available on carbon footprint of particleboard production chain in Pakistan.

## 2. Carbon footprint methodology

### 2.1. System boundary and reference unit

A "cradle to gate" life cycle model was established for particleboard manufactured during the year 2015–2016 using a reference unit of 1.0 $m^3$ of uncoated particleboard produced (Fig. 3). The model was used to quantify GHG emissions during raw materials acquisition, product manufacturing and distribution. The model included the consumption of electricity, fossil fuels, urea-formaldehyde resin and other chemicals, and the transport of secondary materials. The study follows the "World Business Council for Sustainable Development (WBSCD) and World Resource Institute (WRI) Product Life Cycle Accounting and Reporting Standard". According to the demands of the customers, a variety of particle sizes are used and board thicknesses manufactured. For instance, the typical particle sizes are 4880*2440 mm or 2440*1220 mm whereas the board thickness can range from 4 to 25 mm in Pakistan (SMEDA, 2006). The density of particleboard manufactured is usually 750 $kg/m^3$ with a moisture content of 2–5%. Each particleboard industry has its specific process settings; however, the general process flow is common to all of them (Fig. 4).

Wood-based manufacturing processes are commonly multi-functional, i.e. more than one co-product is produced (Malca and Freire, 2006, 2011; Jungmeier et al., 2002a). This requires a decision about how to divide ("allocate') the environmental impacts among the co-products. The particleboard production chain usually consists of two multiple output processes i.e. the sawmill process and the incineration of residues for energy recovery (Santos et al., 2014). However, in Pakistan, more than 80% of particleboard mills consume roundwood (logs) and no wood residues are collected from sawmills. The capital goods production (building site, infrastructure, equipments, their maintenance, repairs & decommissioning), and consumers commuting to and from the point of particleboard purchase were excluded from this study.

### 2.2. Data collection sources and inventory

The primary data for this study were collected as a component of Ph. D research at the Department of Environmental Sciences, Quaid-i-Azam University, Islamabad, Pakistan. Particleboard mills were visited to collect the required information through surveys and interviews with mill managers and workers (Fig. 4). Data regarding production