

Original Article

# Environmental sustainability assessment of wooden furniture produced in Pakistan

## Avaliação da sustentabilidade ambiental de móveis de madeira produzidos no Paquistão

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### Abstract

Life cycle assessment was carried out for a conventional wooden furniture set produced in Mardan division of the Khyber Pakhtunkhwa province of Pakistan during 2018-19. Primary data regarding inputs and outputs were collected through questionnaire surveys from 100 conventional wooden furniture set manufacturers, 50 in district Mardan and 50 in district Swabi. In the present study, cradle-to-gate life cycle assessment approach was applied for a functional unit of one conventional wooden furniture set. Production weighted average data were modelled in the environmental impacts modelling software i.e., SimaPro v.8.5. The results showed that textile used in sofa set, wood preservative for polishing and preventing insects attack and petrol used in generator had the highest contribution to all the environmental impact categories evaluated. Total cumulative energy demand for wooden furniture set manufactured was 30,005 MJ with most of the energy acquired from non-renewable fossil fuel resources.

**Keywords:** furniture, LCA, SimaPro, environmental impacts, Mardan, Pakistan.

### Resumo

A abordagem de avaliação do ciclo de vida foi realizada para um conjunto de móveis de madeira convencional produzido na divisão Mardan da província de Khyber Pakhtunkhwa do Paquistão durante 2018-19. Os dados primários sobre entradas e saídas foram coletados por meio de pesquisas por questionário de 100 fabricantes de conjuntos de móveis de madeira convencionais, 50 no distrito de Mardan e 50 no distrito de Swabi. No presente estudo, a abordagem de avaliação do ciclo de vida do berço ao portão foi aplicada para uma unidade funcional de um conjunto de móveis de madeira convencional. Os dados da média ponderada da produção foram modelados no software de modelagem de impactos ambientais, isto é, SimaPro v.8.5. Os resultados mostraram que os têxteis usados no conjunto de sofás, o preservativo de madeira para polir e prevenir o ataque de insetos e a gasolina usada no gerador tiveram a maior contribuição em todas as categorias de impacto ambiental avaliadas. A demanda total acumulada de energia para o conjunto de móveis de madeira fabricado foi de 30.005 MJ, com a maior parte da energia adquirida de recursos de combustíveis fósseis não renováveis.

**Palavras-chave:** móveis, LCA, SimaPro, impactos ambientais, Mardan, Paquistão.

## 1. Introduction

Wood has been used as an efficient raw material for different purposes such as construction, furniture, locomotive interiors, and packing (Nakano et al., 2018; Gasol et al., 2008). Wood is the most favorable material by the industries (Werner and Nebel, 2007; Wang et al.,

2016) and has multiple benefits such as renewable resource, regenerative fuel, beautiful, pleasant, low weight, high insulation capacity, and act as a carbon sink to fight against climate change; (Puettmann et al., 2010). Wood based industries include wood panels productions, cork,

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pulp and paper and paper-boards productions, wooden furniture production, sports industries and paper-board converting and printing industries (González-García et al., 2011). Wooden furniture industry is one of the oldest industries and it produces different durable products used for sitting, eating, working, lying, storage, and supporting (Cordella and Hidalgo, 2016). Furniture industry uses different raw materials to produce various products such as woods, plastics, textiles, leather and metals (González-García et al., 2012). Wood based products are a carbon reservoir because living trees trapped atmospheric carbon through the process of photosynthesis and absorbed it in their stems. Therefore, wood-based products such as lumber, plywood, fiberboard, etc. reduce the release of stored carbon back into the atmosphere (Karjalainen et al., 2002; Bergman et al., 2014; Skog et al., 2004; Eriksson et al., 2012). Intergovernmental panel on climate change (IPCC) recommended replacement and substitution of energy-intensive non-wood-based products such as iron, steel and plastic with the wood-based products i.e., lumber, particleboard, plywood fiberboard plywood etc. because of its environmentally favorable nature and carbon-neutrality. However, the wood-based products could not be considered carbon-neutral products if the forest management is not on sustainable basis (IPCC, 2006; Hussain et al., 2017, 2018). IPCC reported that about 30% of the total greenhouse gases (GHGs) emissions were contributed by global industrial sector (IPCC, 2014; Kucukvar and Samadi, 2015).

Life Cycle Assessment (LCA) has been recognized the most efficient and sophisticated tool to analyze potential environmental impacts such as ozone depletion potential, eutrophication potential, acidification potential, global warming potential, human toxicity, terrestrial eco-toxicity, marine water eco-toxicity, freshwater eco-toxicity and, photochemical oxidation along all the life-cycle stages of a product and it must be the part of policy-making process for environmental efficient products (ISO, 2006a, b; Baumann and Tillman, 2004). LCA has four stages which consists of (i) goal and scope definition, (ii) life cycle inventory (LCI), (iii) cycle impact assessment (LCIA), and (iv) life cycle results interpretation (Ika Rinawati et al., 2018). Many LCA studies have shown that wooden products generally have favorable environmental profiles as compared with other competing products such as plastics, concrete, steel and iron (Glover et al., 2002; Werner and Nebel, 2007). Many studies have been conducted on LCA of wooden furniture in other countries of the world such as Europe (González-García et al., 2009a), China (Wang et al., 2016), Germany (Wenker et al., 2018), and Brazil (Medeiros et al., 2017). González-García et al. (2012) conducted a comprehensive study on environmental profile of a wooden childhood furniture to propose an effective benchmark for its eco-labeling. The authors applied LCA and Design for Environment (DfE) methods to suggest green and clean substitutes. Likewise, Chaves 2007 conducted studies on LCA of furniture industry to propose better guidelines and greener options for production of sustainable and environmentally preferable wooden furniture products. However, based on our knowledge, so far, no study on LCA of wooden furniture products have been conducted in Pakistan. Presently, furniture markets/sectors become

advanced and they adapted environmental-friendly practices and such practices are being considered as a reliable market tool in furniture manufacture industry (Parikka-Alhola 2008). The deforestation rate is estimated in Pakistan and considered it the second highest in the world (IUCN, 2002). World Conservation Union (IUCN) has investigated that with the increase in the current population growth and the use of wood in Pakistan would be 3% increase per year. Hence IUCN (2002) predicted that if Pakistan continues the same rate of deforestation, there forests will be vanished within coming ten or fifteen years (Ali and Benjaminsen, 2004). In Pakistan Shisham, Oak, Teak, Chir, Kikar, Deodar woods and bamboo were utilized for furniture manufacture but now a day's wood panels are mostly used. There are about 60% particleboards are used in Pakistan (Hussain et al., 2017). Pakistan forest cover is 4.2 million hectares which is about 4.8% of the overall land area of the country (Zaman and Ahmad, 2011). Due to rapid increase in population forest cover is also decreasing, because the local people depend on forest resources i.e., house construction, ecotourism, wooden furniture manufacture, fuelwood, and medicinal plants extraction. From 1996 to 2000 about 2.35 million m<sup>3</sup> round wood was extracted for industrial use. This study was aimed with the objective was to conduct the life cycle assessment of the wood-based furniture in the Mardan division, KP, to investigate the impacts on local forest and to identify sustainable strategies or greener options for wood-based furniture manufacture in the study area.

## 2. Materials and Methods

### 2.1. Study area

The present study was conducted in Mardan division of Khyber Pakhtunkhwa province which comprises of two districts i.e., Mardan and Swabi as can be seen in Figure 1. Mardan district lies on 34° 12' 22.0428" N and 72° 1' 47.2800" E with an elevation of 314 m. District Swabi lies on 34° 7' 0" N, 72° 28' 0" E with an elevation of 340 m. In this study about 100 furniture industries were visited and considered for data collection, where 100 questionnaires were filled 50 in district Mardan and 50 in district Swabi.

### 2.2. Study design

#### 2.2.1. Goal and scope definition

The study aim was to conduct a cradle-to-gate life cycle assessment (LCA) of wooden furniture and to identify or investigate the environmental impacts of the wood-based furniture i.e., sofa set, double bed, cupboard, showcase, dressing table, general table and to determine materials flow, energy use, and emission to water, soil and air caused during the production of wood-based furniture set. In addition, to investigate energy sources utilized by wood-based furniture set and their associated environmental impacts and to estimate the deforestation in Mardan Division, KP.

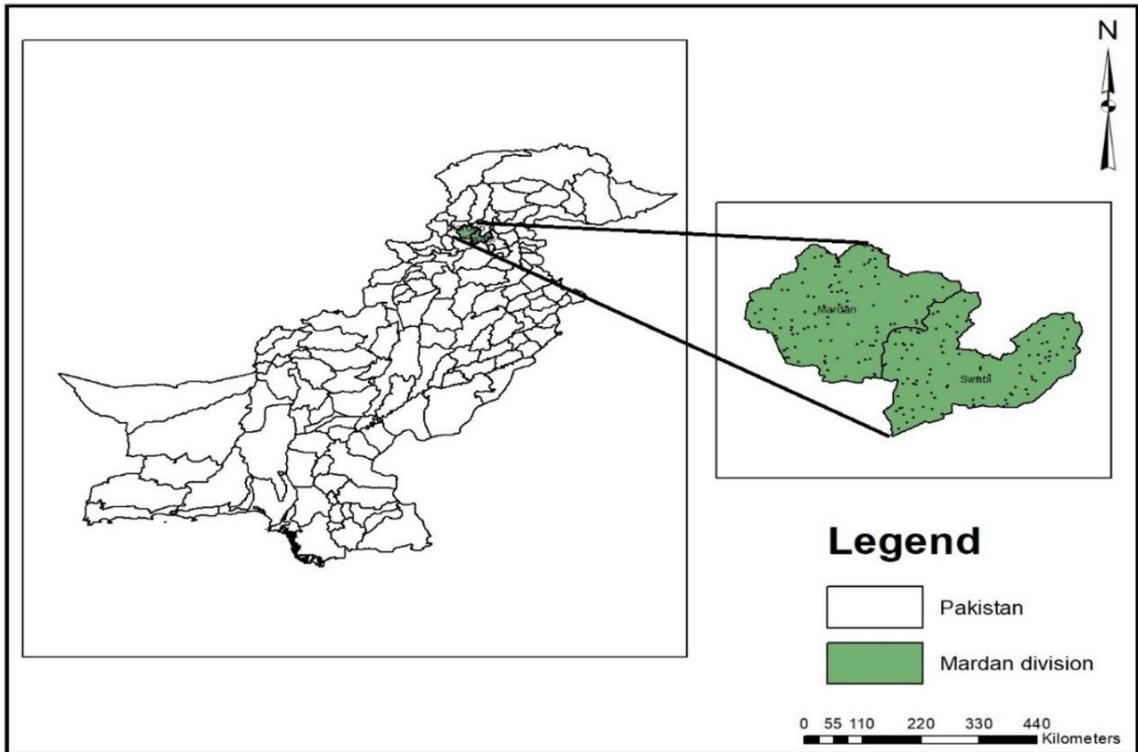


Figure 1. Location map of the study area.

### 2.2.2. Functional unit

A conventional marriage wood-based furniture set was the functional unit which was considered in the present study. In this study materials used, energy consumption and associated emission (Air, water, and soil) data have been normalized for functional unit of wood-based furniture set in Mardan Division, KPK during 2018-19. The furniture set comprised of double bed, sofa set, show case, cupboard, dressing table and general table. These furniture products were selected because in our culture it is necessary from a bride side to buy these furniture products for their daughters in weddings or marriage ceremony. The standard furniture which is made for every marriage consists of simple double bed, sofa set, show case, cupboard, dressing table and general table. In the present study about 90% of the people ordered a conventional marriage wooden furniture set for their daughter's and/or sisters' marriage, however only the rich peoples demand for a unique or antique furniture for their daughter's/sister's dowry.

### 2.2.3. System boundary of the study

System boundary of the study is presented in Figure 2. System boundary of the present study comprised of the main life cycle stages of wood-based furniture manufacture in Mardan division, KP i.e., from forest harvesting/deforestation, in this step forest trees were cut down and then round logs were taken by vehicle to the sawmill for sawing, after sawing the planks were made and then taken

to the furniture industry/shops where manufacturing take place after that surface treatment of the products was done. After the surface treatment the finished products packaging was done and then transport to the distribution centers.

### 2.2.4. Life cycle inventory

A detailed questionnaire-based surveys were conducted in Mardan Division and data about inputs/outputs, energy consumption was collected. A total of 100 local furniture industries/shops were visited for the collection of relevant data in the study area. 50 questionnaires were filled in each district. Production-weighted average values were calculated for the primary data from the hundred furniture industries/shops (Equation 1). The variation in the data was calculated as the weighted coefficient of variation ( $CV_w$ ) using Equations 2 and 3 below.

$$\bar{x}_w = \frac{\sum wx}{\sum x} \quad (1)$$

$$Sd_w = \sqrt{\sum_{i=1}^N w_i (X_i - \bar{x}_w)^2 \times \frac{N'}{(N'-1) \sum_{i=1}^N w_i}} \quad (2)$$

$$CV_w = \frac{Sd_w}{\bar{x}_w} \quad (3)$$

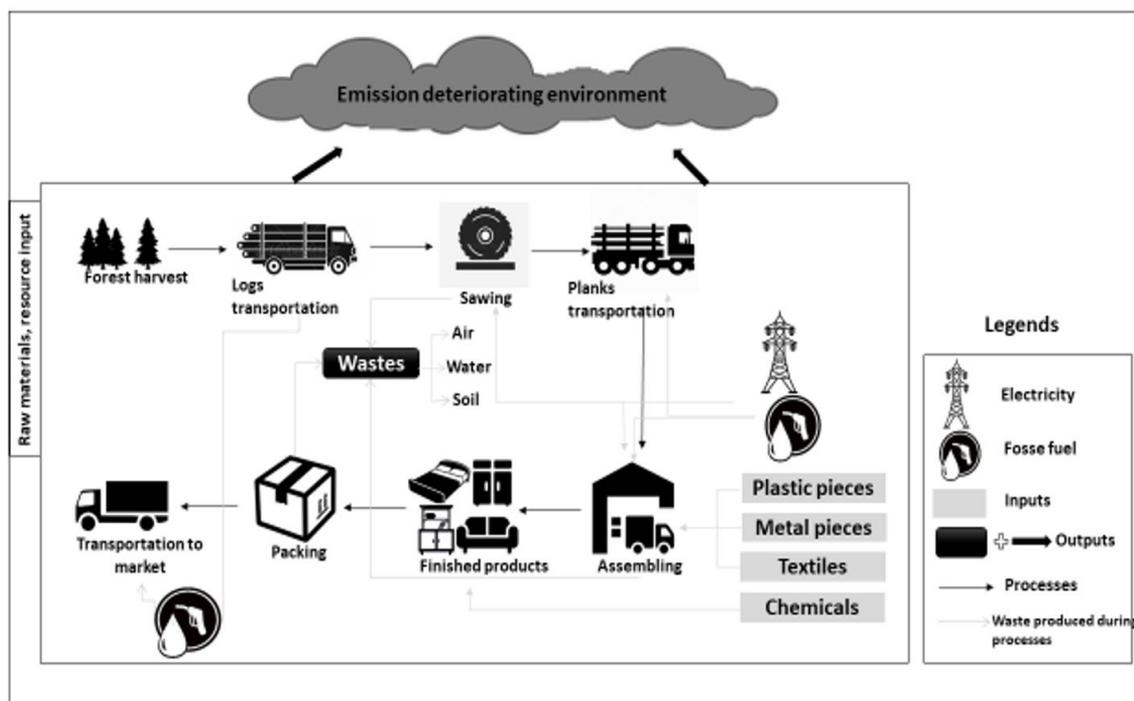


Figure 2. System boundary of the study.

### 2.2.5. Life cycle impact assessment

The data was analyzed by using SimaPro v8.5 (Wang et al., 2016; Mirabella et al., 2014). This software was developed by PRÉ-Consultants (González-García et al., 2011). The environmental impact categories were analyzed by using CML 2 baseline 2000 V2.05 methodology in the SimaPro v 8.5 (Wang et al., 2016; Mirabella et al., 2014). Cumulative energy demand (CED) was evaluated for wood-based furniture set in Mardan Division during 2018-19. The CED subcategories were, non-renewable nuclear, renewable biomass, renewable water and non-renewable fossil (Wang et al., 2016). The allocation of resource input and outputs and their associated impacts were mass-based (Hussain et al., 2017). In SimaPro v8.5 some substances were not presented in the Eco-invent database such as shellac, nail and sandpaper because it was a faculty licensed. Shellac act as a wood preservative and in SimaPro v.8.5 software shellac was not available as such, so we used wood preservative instead of shellac, sand paper is coated with aluminum oxide, so we used aluminum oxide instead of sand paper, and instead of nail, steel was used in the Eco-invent database in SimaPro v8.5 software for analysis. Estimation of deforestation or wood consumed was calculated into cube meter (m<sup>3</sup>) unit by using the formula. The wood used in the furniture manufacture data (t dm) were converted into cubic meters by dividing the quantity of wooden mass by density of the species. A variety of tree species (Shisham (*Dalbergia sissoo*) and kikar (*Acacia nilotica*)) in variable quantities were used for wooden furniture manufacturing, therefore a general value of wood density for different tree species were applied to convert wood consumption data into the volume unit

e.g., 0.85 t dm/m<sup>3</sup> and 0.75 t dm/m<sup>3</sup>. Wood consumption is usually estimated in unit of cubic meter (m<sup>3</sup>).

### 2.3. Estimation of carbon stored, carbon stock, carbon footprint, and net carbon flux

According to Consortium for Research on Renewable Industrial Materials (CORRIM) guidelines 52.4% carbon is stored in biomass (Puettmann et al., 2010; CORRIM, 2001). Therefore, carbon contents in woody biomass were calculated using CORRIM guideline in the present study. Likewise, carbon footprint can be defined as the sum of all the GHG emissions directly or indirectly caused by a product, or process, usually quantified in mass of carbon dioxide equivalents (CO<sub>2</sub>e) (Hussain et al., 2017, 2018). Carbon footprint was calculated for wooden furniture set by using SimaPro v 8.5 software. Net carbon flux was calculated for wooden furniture set by subtracting carbon footprint from carbon stock for one conventional wooden furniture set manufactured during 2018-19.

## 3. Results and Discussion

### 3.1. Life cycle inventory of inputs and outputs for one wooden furniture set

The materials that were used for unit wood-based furniture set production as an inputs and outputs are listed in Table 1. In the present LCA study a conventional marriage wood-based furniture set was considered which comprised of sofa set, cupboard, showcase, double bed, dressing table and general table. About (2984 kg) round

**Table 1.** Material inputs/output for unit wood-based furniture set manufactured in Mardan division during 2018-2019.

Input/output	Unit	Sofa set	Cupboard	Showcase	Double bed	Dressing table	General table	Total
Wood logs and wood panels	kg	522	410	421	640	371	620	<b>2984</b>
Sawdust	kg	72	52	36	43	52	60	<b>315</b>
Electricity	kWh	19	10	8	11.3	8	9	<b>65.3</b>
Urea formaldehyde (UF) resin	kg	0.6	0.62	0.6	0.6	0.6	0.6	<b>3.62</b>
Nail, handles, clips and magnet (Steel)	kg	0.6	1.1	1.1	2	1	0.6	<b>6.4</b>
Lock (Zinc)	kg	-	0.7	0.5	-	0.5	-	<b>1.7</b>
Petrol	L	27	27	27	27	27	27	<b>162</b>
Glass	kg	-	-	23.2	-	17	-	<b>40.2</b>
Cloth used (Textile)	kg	20	-	-	-	-	-	<b>20</b>
Foam (Polypropylene foam)	kg	15	-	-	-	-	-	<b>15</b>
Delivery distance of wood	km	1.2	1.2	1.2	1.2	1.2	1.23	<b>7.23</b>
Delivery distance of UF resin	km	0.05	0.05	0.05	0.05	0.05	0.05	<b>0.3</b>
Sprit	L	2.7	4	4	4	4	3	<b>21.7</b>
Shellac (Wood preservative)	kg	2	2	2	2	2	2	<b>12</b>
Cloth used for polish (textile)	kg	1.3	1.3	1.3	1.3	1.3	1.3	<b>7.8</b>
Sandpaper (Aluminum oxide)	kg	1.3	1.3	1.3	1.3	1.3	1.3	<b>7.8</b>
Lime	kg	0.7	1	1	1	1	1	<b>5.7</b>
Color/dye (Powder)	kg	0.5	1	1	1	1	1	<b>5.5</b>

logs and wood panels were used in unit wood-based furniture set (Table 1) in which highest wood and wood panels was consumed in general table (620 kg) and lowest was in dressing table (371 kg). Round wood was acquired from local agroforestry plantations while wood panels were brought from local wood panel wholesale dealers. Our results were in accordance with other studies conducted on LCA of wood-based furniture production, where about (1240 kg) round-wood was used for furniture manufacture in Spain (González-García et al., 2011), (678 kg) in China (Wang et al., 2016) and (173 kg) Finland (Linkosalmi et al., 2016). The primary reason for less consumption of round-wood and wood panels in other countries were used of metal and plastic pieces with round-wood and wood panels in furniture products

while in the present study furniture set was completely made of pure wood and wood panels. In the production of unit wood-based furniture set, (315 kg) sawdust/wood waste was produced highest sawdust/ wood waste was produced in sofa set production (72 kg), and lowest was in general table (60 kg). While cutting the logs into desirable sizes, wood residues are produced which are used as a fuelwood in homes and factories (Bergman et al., 2014; Milota et al., 2007), whereas the saw dust produced is further mixed with urea formaldehyde (UF) resin and used to fill the cracks or hollow spaces in the wood-based doors, windows and furniture. The sawdust is also sold out to the poultry industry for bedding purpose to the chicks (Hussain et al., 2017). Our results are in line with Wang et al. (2016), revealed that about (21 kg) sawdust was

produced during furniture production in China and 10 kg sawdust was produced in Brazil (Medeiros et al., 2017).

About (65.3 kWh) purchased electricity was consumed to produce unit wood-based furniture set in the study area. Electricity consumption in sofa set was high (19 kWh) and was less in double bed production (11.3 kWh). The electricity was purchased from national grid station which is the main source of power to run the machines in wood-based furniture industry in the study area. About (90%) of Pakistan's electricity is from hydel power. However, in developed countries they generate electricity through multiple sources such as nuclear and fossil fuels. Similar study was conducted by Wang et al. (2016) in China and the result revealed that electricity consumption was (108 kWh), in Spain (604 kWh) (González-García et al., 2011) in Finland (160 kWh) (Linkosalmi et al., 2016) in furniture production. The main reason was that most of the electricity was consumed in making wooden frame making, upholstering process of textile and packaging of the finished product. Approximately (3.62 kg) of urea formaldehyde (UF) resin was utilized. UF resin was used to bind the joints of two planks to make the joint more durable and was also used to fill the cracks (Hussain et al., 2017). Similar study was conducted in China and they used spraying glue (0.32 kg) and polyvinyl acetate (PVAs) glue (0.3 kg) (Wang et al., 2016) and in Turkey (0.4 kg) UF resin was consumed (Mermertas et al., 2018) in Finland (2.9 kg) (Linkosalmi et al., 2016). The major reason for high use of UF resin in our study was because of our furniture set was completely made of wood material and UF resin was used with every plank during assembling while in other studies different materials were utilized with wood material i.e. metals (aluminum) and plastic in production of furniture set so that is why less UF resin was consumed. In the present study about (6.4 kg) of nail, handles, magnets and clips were used in the production wood-based furniture set. Nail was used in unit furniture set to hold two planks. Handles were used in cupboard, showcase and dressing table doors and drawer for holding while magnets were utilized to keep the doors close automatically. In cupboard, showcase and dressing table doors and drawers approximately (1.7 kg) lock was utilized. These locks were used to lock the doors and drawers. Clips were used only in double bed to tighten the side main planks and to make the double bed more load bearer. Our results are similar with (Wang et al., 2016) China where about (4.5 kg) steel was consumed and in Finland (75 kg) steel was utilized (Linkosalmi et al., 2016). The primary reason for highest use of steel in Finland was because they used screws as well as steel parts in chairs, desks, and cabinet.

To produce unit wood-based about (162 L) petrol was consumed. About (27 L) petrol was used in each item. In Pakistan the energy crises are at peak, to tackle energy or power crises WAPDA do load shedding about 3 to 6 hours daytime. So, during load shedding time the manufacturers used electric generator to produce electricity to run the machines in the shop (Hussain et al., 2017). These generators were run by using petrol. In the present study about (40.2 kg) glass was utilized in showcase and dressing table production in the study area in which 23.2 kg was in showcase and (17 kg) was in dressing table. There is no

literature available for glass utilization to justify our results. Approximately (20 kg) of cloth was utilized in only one in sofa set production. Cloth was used to cushion the sofa set and to make the sofa set look pleasant. Our results are in line with other studies such as in Turkey Mermertas et al. (2018) utilized (4.520 kg) cloth (textile), in Sweden (4.73 kg) cloth was consumed (Dhingra and Gavrish 2016) and in China (4.32 kg) cloth was used (Wang et al., 2016). The cloth consumed in the present study was documented in high amount because our sofa set consists of one large size sofa and two small sizes while in other studies cloth was used only in large size sofa. Around (15 kg) polyethylene foam was consumed in single sofa set production as listed in Table 1. Polyethylene foam was used to make the sofa set comfortable for setting. Similar study was conducted in Turkey on environmental sustainability of a sofa and they also used polyethylene foam (0.052 kg) (Mermertas et al., 2018), in China (1.13 kg) foam was consumed (Wang et al., 2016), Taiwan (23 kg) foam was used (Chou and Chen, 2011) and in Sweden (4.15 kg) was utilized (Dhingra and Gavrish, 2016). The major reason for less amount of polyethylene foam usage in other studies is due to the utilization of other alternative materials such as Polypropylene fiber and Polyethylene foam (Mermertas et al., 2018).

The average delivery distance of wood logs and panels for unit wood-based furniture production was (1.2 km) while for UF resin the average delivery distance was (0.05 km) as summarized in Table 1. Wang et al. (2016) conducted a same study in China and the average delivery of wood log was (1.41 t.km). About (21.7 L) spirit was used in unit wood-based furniture set manufacture. In sofa set production consumed (2.3 L) spirit was utilized while in cupboard, showcase, double bed, and dressing table production (4 L) was consumed and in general table (3 L) was used. Spirit was used in polishing of the sofa set and to prevent from insects such as termites. Our results are in accordance with other studies conducted in Turkey (Mermertas et al., 2018) and the results revealed that polyester resin (0.231 kg) was used for polishing while in Finland acrylic lacquer (2.3 kg) was utilized for shining purposes (Linkosalmi et al., 2016). In unit wood-based furniture set production (12 kg) shellac was consumed as a wood preservative. About (4 kg) shellac was consumed in each item. Shellac was in solid form when boiled in water it converted into firm liquid then applied on sofa set. The liquid shellac is very shining, so it gives a pleasant look to the sofa set. Similar study was conducted in Brazil where 4.82 kg varnish was used (Iritani et al., 2015). Around (7.8 kg) cloth was used in the present study. About (1.3 kg) cloth was consumed in each item of unit furniture set. This cloth was used as a brush to apply the paints or varnished on the furniture items. Approximately (7.8 kg) of sandpaper was consumed in unit wood-based furniture set. It was used to make the planks surface smooth of each item i.e., sofa set, cupboard, showcase, double bed dressing table and general table. In the present study about (5.7 kg) lime was used in unit wood-based furniture. This was used to fill the cracks in each item of the furniture. In unit wood-based furniture set production (5.5 kg) color/dye was consumed. There were three colors (brown, golden and black) utilized in the study area. These colors were in powder form it was

mixed with liquid shellac and then applied on unit furniture. Our results are in line with other studies conducted in Finland (Linkosalmi et al., 2016) and Brazil (Iritani et al., 2015) where (0.191 kg) and (4.82 kg) powder paint was consumed respectively. The highest value of powder color/dye in the present study was because we applied in all the item while in other study it was used only on one item i.e., public space chair (Linkosalmi et al., 2016).

### 3.2. Environmental impacts posed by one wooden furniture set

Environmental impacts posed by unit wooden furniture set production in Mardan division during 2018-19 are tabulated in Table 2. The ten environmental impact categories that were considered in this study were marine aquatic eco-toxicity, ozone layer depletion, abiotic depletion, eutrophication, acidification, human toxicity, fresh water aquatic eco-toxicity, photochemical oxidation, terrestrial eco-toxicity and global warming potentials. The highest environmental impact was posed by marine aquatic eco-toxicity (10,04,804 kg 1,4-DB eq) followed by global warming potentials (1,369 kg CO<sub>2</sub> eq) and abiotic depletion (12.9 kg Sb eq). In general table marine aquatic eco-toxicity was high (3,40,847 kg Sb eq) and was low in dressing table (8,1,830 kg Sb eq). The highest global warming was caused in sofa set production (540 kg CO<sub>2</sub> eq) and lowest was in dressing table (79 kg CO<sub>2</sub> eq). Highest abiotic depletion was posed in the production sofa set and lowest was in cupboard manufacture (1.2 4 kg Sb eq). The major contributor to the potential environmental burden categories were from cloth (textile), shellac (wood preservatives), foam and petrol used in electric generator to produce electricity. Our results are in line

with other studies conducted by Wang et al. (2016) China and Mermertas et al. (2018) Turkey, their results revealed that in manufacturing of wood-based furniture production, transportation of raw materials and textile have the highest contribution to environmental impacts.

Abiotic is the most considered category in environmental burdens in life cycle assessment. Abiotic depletion was estimated (12.9 kg Sb eq) for unit wood-based furniture set production in the study area during the year 2018-19. Highest abiotic depletion was caused by the production of sofa set and general table (4 kg Sb eq) and lowest was by dressing table (1.2 4 kg Sb eq), respectively. Our results agree with other studies where wooden material production, raw materials transportation, and textile production was the main cause of abiotic depletion. (Wang et al., 2016; Mermertas et al., 2018). In the present study, acidification estimated for unit wood-based furniture set production in Mardan Division was (8.68 kg SO<sub>2</sub> eq). Acidification was high in sofa set and general table production (3 kg SO<sub>2</sub> eq) and was low in double bed (0.6 kg SO<sub>2</sub> eq), respectively. Our results are in line with other studies conducted in Brazil, where input materials supply, and product distribution was the main cause of acidification (Iritani et al., 2015). While in China and Turkey raw materials transportation, and textile production was the main cause of Acidification (Wang et al., 2016; Mermertas et al., 2018).

The value of eutrophication was 2.91 kg PO<sub>4</sub> eq for unit wood-based furniture set production in the study area. In the present study the highest value of eutrophication was found in sofa set manufacture (1.13 kg PO<sub>4</sub> eq), and lowest was in showcase production (0.18 kg PO<sub>4</sub> eq). Our results are similar to Mermertas et al. (2018) Turkey and Wang et al. (2016) China, where textile used was responsible for eutrophication.

**Table 2.** Environmental impacts posed by unit wood-based furniture set manufactured in Mardan division during 2018-19.

Impact categories	Unit	Sofa set	Cupboard	Showcase	Double bed	Dressing table	General table	Total
Abiotic depletion	kg Sb eq	4	1.2	1.3	1.2	1.2	4	<b>12.9</b>
Acidification	kg SO <sub>2</sub> eq	3	0.6	0.78	0.6	0.7	3	<b>8.68</b>
Eutrophication	kg PO <sub>4</sub> eq	1.13	0.2	0.18	0.2	0.2	1	<b>2.91</b>
Global warming potentials	kg CO <sub>2</sub> eq	540	64	84	63	79	539	<b>1369</b>
Ozone layer depletion	kg CFC-11 eq	0.002	0.00003	0.00003	0.00003	0.00003	0.0018	<b>0.00392</b>
Human toxicity	kg 1,4-DB eq	313	104	96	104	99	315	<b>1031</b>
Fresh water aquatic eco-toxicity	kg 1,4-DB eq	767	36	34	36	35	767	<b>1675</b>
Marine aquatic eco-toxicity	kg 1,4-DB eq	340010	82731	79692	79694	81830	340847	<b>1004804</b>
Terrestrial eco-toxicity	kg 1,4-DB eq	57	0.6	0.49	0.53	0.55	57	<b>116.17</b>
Photochemical oxidation	kg C <sub>2</sub> H <sub>4</sub> eq	0.13	0.03	0.04	0.03	0.04	0.13	<b>0.4</b>

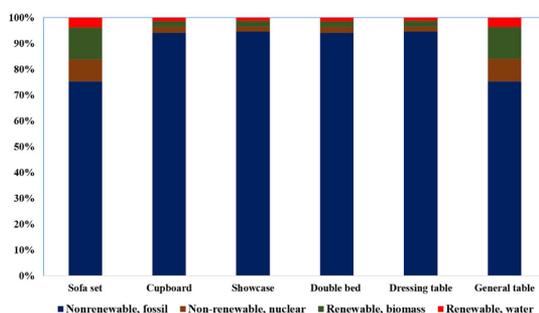
About 1,369 kg CO<sub>2</sub>-eq global warming potential was estimated for unit wood-based furniture set production in Mardan division. Global warming value was high in sofa set production (530 kg CO<sub>2</sub>-eq) and was low in double bed manufacture (63 kg CO<sub>2</sub>-eq). Similar study was conducted by Iritani et al. (2015), in Brazil, Medeiros et al. (2017) in Germany and the results revealed that most of the global warming potential was caused by raw materials availability and use of medium density particleboard. Mermertas et al. (2018) in Turkey also reported that raw material transportation and textile production was responsible for higher global warming potential. The value of ozone layer for unit wood-based furniture set was (0.00392 kg CFC-11 eq) in the study area. In the present study highest value for ozone layer depletion was in sofa set manufacture (0.002 kg CFC-11 eq), followed by general table (0.0018 kg CFC-11 eq), cupboard, showcase, double bed, and dressing table (0.00003 kg CFC-11 eq), respectively. The highest emission was caused by textile in sofa set manufacture in the study area. (>95%). Our results are similar with Iritani et al. (2015) Brazil and Medeiros et al. (2017) Germany, where raw materials supply for paperboard and medium density fiberboard and electricity consumption for wood panels was the main reason for ozone layer depletion.

About (1,031 kg 1,4-DB eq) human toxicity was estimated for unit wood-based furniture set production in Mardan division. Highest human toxicity was found in the production of general table (315 kg 1,4-DB eq), and lowest was in showcase (96 kg 1,4-DB eq). Our results agree with Iritani et al. (2015) Brazil and Medeiros et al. (2017) Germany where raw material transportation and UF resin used in medium density particleboard production caused the highest human toxicity. Ika Rinawati et al. (2018) in Indonesia highest human toxicity was caused during electricity production. In the present approximately Fresh water aquatic eco-toxicity (1,675 kg 1,4-DB eq) was investigated for unit wood-based furniture set in the study area. Fresh water aquatic eco-toxicity value was high in sofa set and general table manufacture (767 kg 1,4-DB eq) and was low showcase (34 kg 1,4-DB eq). Similar study was conducted in Germany where wastes produced, raw materials transportation and medium density particleboard production have caused highest fresh water aquatic eco-toxicity (Medeiros et al., 2017). The value of marine aquatic eco-toxicity in the production of sofa set in Mardan division was (1,004,804 kg 1,4-DB eq). this was the highest value recorded of the environment impact categories in unit wood-wood based furniture production in the study area. In the present study highest value for marine aquatic eco-toxicity was investigated in general table production (3,40,847 kg Sb eq) and lowest was in showcase (79,692 kg Sb eq). The primary reason for these higher impacts in fresh and marine water bodies is due to release of VOCs and hydrocarbons to air which ultimately comes to water through hydrological cycle (Hussain et al., 2017). Similar study was conducted by Mirabella et al. (2014) Italy and the results revealed that most of the eutrophication was caused by iron production that were used in wooden furniture, solid wood panels production and paints.

About (116.17 kg 1,4-DB eq) was calculated for unit wood-based furniture set production in Mardan division. The value for terrestrial eco-toxicity was high in sofa set and general table manufacture (57 kg 1,4-DB eq) and was lowest in showcase (0.49 kg 1,4-DB eq). Our results are with agreement with Mirabella et al. (2014) Italy where iron parts and solid wood panel production was the primary reason for terrestrial eco-toxicity, the emission caused during solid wood production the emission of phosphorous and vanadium was caused from heavy fuel use production. The value of photochemical oxidation in the production of unit wood-based furniture set in Mardan division was (0.4 kg C<sub>2</sub>H<sub>4</sub> eq). In the present study highest value of photochemical oxidation was in the manufacture of sofa set and general table (0.13 kg C<sub>2</sub>H<sub>4</sub> eq) and was low double bed (0.03 kg C<sub>2</sub>H<sub>4</sub> eq), respectively. Our results are in line with Mirabella et al. (2014) Italy and the results showed that highest photochemical oxidation was caused by heavy fuel in the production of solid wood panels for furniture. Iritani et al. (2015) Brazil where raw material supply and medium density particleboard production was the main reason of photochemical oxidation.

### 3.3. Cumulative energy demand for wooden furniture set production

Cumulative energy demand (CED) is defined as to quantify the total energy required to produce, use and end-life of a product. CED is a method or way to investigate, examine and declare the product as a sustainable on the bases of energy (Mert et al., 2017). The four impact categories that were investigated in the present study were renewable water, renewable biomass, non-renewable nuclear, and non-renewable fossil as summarized in Table 3 and Figure 3. During the production process different types of energy was required to run the machines for the manufacturing of unit wood-based furniture set in Mardan Division during 2018-19. Electricity was the main energy source to run the saw for cutting the round logs and wood panels into desirable size and transportation of raw materials. In the present study total CED for unit wood-based furniture set production in Mardan Division during 2018-19, was (30005 MJ) from the four impact categories i.e., renewable water, renewable biomass, non-renewable nuclear, and non-renewable fossil. The highest



**Figure 3.** Cumulative energy demand for unit wood-based furniture set production in Mardan division during 2018-19.

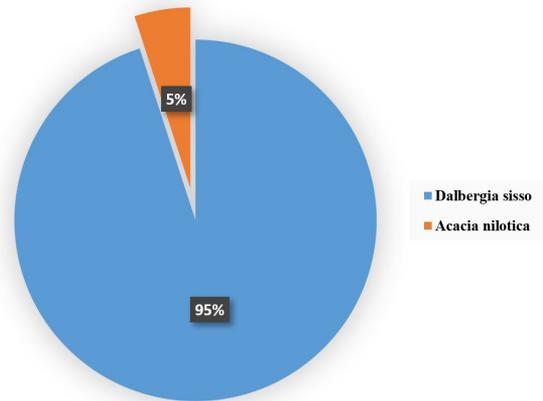
**Table 3.** Cumulative energy demand for unit wood-based furniture set produced in Mardan division during 2018-19.

Impact categories	Unit	Sofa set	Cupboard	Showcase	Double bed	Dressing table	General table	Total
Nonrenewable, fossil	MJ	7186	2465	2689	2460	2689	7196	<b>24685</b>
Non-renewable, nuclear	MJ	824	55	53	55	53	828	<b>1868</b>
Renewable, biomass	MJ	1171	61	65	61	65	1169	<b>2592</b>
Renewable, water	MJ	365	36	34	36	34	355	<b>860</b>
<b>Total</b>								<b>30005</b>

contribution was from the non-renewable fossil fuels-based energy (24685 MJ) and the lowest contribution was from renewable water (860 MJ). In general table highest energy was acquired from non-renewable fossil fuels which was 7196 MJ followed by sofa set (7186 MJ), showcase and dressing table (2689 MJ), cupboard (2465 MJ), and double bed (2460 MJ). In sofa set production highest energy was consumed from renewable biomass (1171 MJ) and lowest was in double bed (61 MJ). Highest non-renewable nuclear energy was consumed in general table (828 MJ) and lowest was in showcase and dressing table (53 MJ). In sofa set production highest energy was acquired from renewable water which was (265 MJ) and double bed (36 MJ), and was low in showcase and dressing table (34 MJ). All these energies were utilized during the production of electricity and its consumption and transportation of raw materials. Due to the lack of literature availability on cumulate energy demand for unit wood-based furniture set we compared our CED results with wood panel industry to justify our results similar studies was conducted by Hussain et al. (2017) and Iritani et al. (2015) and the results showed that most of the energy was used from nonrenewable fossil during transportation and distribution of inputs/outputs, urea formaldehyde production and electricity generation and consumption during all the process.

#### 3.4. Volume of total wood harvest for unit wood-based furniture set production

Based on our survey's information, the total wood consumption of different tree species for unit wood-based furniture set, in Mardan division, KP was equal to 2984 kg during 2018-19. The highest consumption was noted for by *Dalbergia sissoo* (95%), followed by *Acacia nilotica* (5%) during 2018-19, as can be seen in Figure 4. All these tree species are grown in the form of agroforestry plantations in the agricultural fields in the study area. These tree species are mostly fast-growing species which do not require any additional inputs of fertilizer, pesticides and water etc., because they are grown on the shelter belts and boundaries of the agricultural fields in the study area. The highest consumption of *Dalbergia sissoo*, *Acacia nilotica* in Mardan division, KP is attributed to the farmer's choice or selection of these tree species to plant in their agricultural fields because of its fast growth, suitability with local climatic conditions and high demand in local market. Agroforestry plantations and private farmlands provide 86% timber and 90% fuelwood supplies to the

**Figure 4.** Deforestation species wise for unit wood-based furniture set.

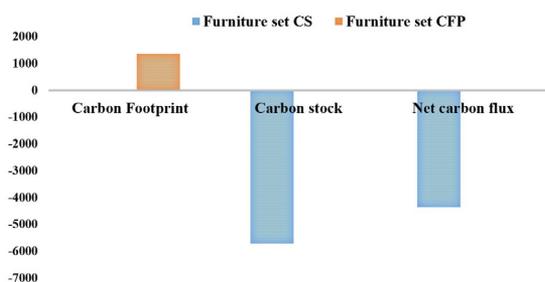
households in Pakistan (Hussain et al., 2017). In addition, about 60% of the urban and 90% of the rural households in Pakistan consumes fuelwood for primary energy needs such as heating and cooking (Tahir et al., 2010). However, Pakistan has insufficient forest resources and the total area covered by forest is less than 5% and is going to be further decreased due to deforestation and commercial over exploitation, because the annual deforestation rate is 2.1%, which is highest among all the south Asian countries (GOP, 2010). The relative contribution of *Dalbergia sissoo* to total wood harvest or deforestation was estimated to be 2835 kg based on its density 0.37 kg dry mass (kg d m/set) whereas the density of *Acacia nilotica* is 0.35 kg d m/set which caused 149 kg deforestation. However, the least contribution to deforestation was estimated for *Acacia nilotica*, which was 149 kg/set with a wood density of 0.74 kg d m/set in the study area.

#### 3.5. Carbon footprint, carbon stock and net carbon flux of unit wood-based furniture set

Carbon footprint can be defined as sum of all the GHG emissions directly or indirectly caused by a product, process, organization or even a person, usually quantified in terms of tonne or kilogram of carbon dioxide equivalents (CO<sub>2</sub>e) (Hussain et al., 2017, 2018). The percent average carbon content in wood was considered 52.4% of the mass, according to CORRIM guidelines for performing

**Table 4.** Carbon footprint, carbon stock and net carbon flux of unit wood-based furniture set.

Item	wood used (kg)	Stored Carbon (kg)	Carbon stock (kg)	Carbon Footprint (kgCo2e)	Net carbon flux (kgCo2e)
Sofa set	522	273	-999	540	-459
Cupboard	410	215	-787	64	-723
Showcase	421	220	-805	84	-721
Double bed	640	335	-1226	63	-1163
Dressing table	371	194	-710	79	-631
General table	620	324	-1186	539	-647
<b>Total</b>	<b>2984</b>	<b>1561</b>	<b>-5713</b>	<b>1369</b>	<b>-4344</b>

**Figure 5.** Carbon footprint (CFP), carbon stock (CS) and net carbon flux of unit wood-based furniture set.

life cycle inventories on wood products (Puettmann et al., 2010; CORRIM, 2001). The total carbon content stored in wooden furniture set in Mardan division, KP, Pakistan was (1561 kg) as shown in Table 4 and Figure 5, in which highest carbon was trapped in double bed (335 kg), and lowest was in general table (324 kg). The total carbon stock for unit wood-based furniture in Mardan division during 2018-19 was (-5713 kg) in which highest carbon stock was of cupboard (-787 kg), and lowest of double bed (-1226 kg). In the present study the total carbon footprint for wooden furniture set was (1369 kg CO<sub>2</sub> eq) in which sofa set carbon footprint was (540 kg CO<sub>2</sub> eq) which was high and lowest was double bed (63 kg CO<sub>2</sub> eq). Total net carbon flux for wooden furniture set in the study area was (-4344 kg CO<sub>2</sub> eq) in which sofa set was (-459 kg CO<sub>2</sub> eq), double bed (-1163 kg CO<sub>2</sub> eq).

#### 4. Conclusions and Recommendations

This paper aimed to conduct the life cycle assessment of wood-based furniture industry and its impacts on local forests of Mardan division, KP, Pakistan. Life cycle inventory data for hardwood lumber manufacture were collected from hundreds (100) furniture shops/industries. The results indicate that textile, petrol, and wood preservatives use had the highest contribution to all the environmental impacts evaluated. In the wooden furniture manufacturing processes, textile was consumed in high amount in sofa set production which has highest contribution in environmental burdens. So, change textile with other materials can lower

environmental impacts. The total cumulative energy consumed by unit wood-based furniture set production, was (30005 MJ) The highest contribution was from the non-renewable fossil fuels-based energy (24685 MJ). The most commonly used tree species were by *Dalbergia sissoo* (95%), and *Acacia nilotica* (5%). This is the first LCA study of wooden furniture industry in Pakistan, which illustrated total emissions from the raw materials transportation, wooden furniture production, purchased electricity, fossil fuels used in generators in the furniture shops/industry and final product distribution to the market. The research findings also act as a benchmark for other wood-based industries in Pakistan for future research to formulate plans to reduce environmental impacts. There was no furniture industry/shop in the study area that has installed pollution control devices/systems. So, it is highly recommended to install pollution control systems and other precautions to diminish environmental burdens from furniture industry manufacturing process in Mardan division, Pakistan. Use of renewable energy sources such as petrol, solar energy sources instead of fossil fuels such as petrol is also recommended to avoid and minimize GHG and other toxic emissions from wooden furniture set manufacturing process in the study area. Use other competent materials instead of textile (cloth) in sofa set cushion.

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