Environmental benefits of natural fibre production and use

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Introduction

The year 2009 has been assigned by the UN to be the international year of natural fibres. Natural fibre industries employ millions of people all over the world, especially in the developing countries. As the major non-food commodity natural fibres and their products are processed in many small and large industries and consumers all over the world profit from the provided products. The promotion of the use of natural fibres as CO_2 neutral resource is believed to contribute to a greener planet. So the question arises: how can the evolvement of the global bio-based economy be the solution for sustainable developments? And are natural fibres the solution towards environmental improvement? This paper addresses the various issues that occur when the environmental impact of natural fibres is critically evaluated.

The transition towards a bio-based economy and sustainable developments as a consequence of the Kyoto protocols on greenhouse gas reduction and CO_2 neutral production offers high perspectives for natural fibre markets. Changing to a bio-based economy requires substitution of common raw materials that are currently largely produced from fossil (petrochemical) or mineral resources, by products produced from renewable (plant and animal based) resources. Development of a sustainable global economy, which permits improving purchasing power and living standards without exhaustion of resources for future generations, requires a fundamental change in attitude. On ecological grounds products should then be preferred that are based on photosynthetic CO_2 fixation. The benefit of those sustainable resources is that they can be regrown within the foreseeable future, without negative side-effects on global bio-diversity. Therefore, competitive products based on renewable resources need to be developed that have high quality, show excellent technical performance and harm the environment less than current products based on petrochemical materials.

Definition of natural fibre

Natural fibres can be defined as bio-based fibres or fibres from vegetable and animal origin (table 1). This definition includes all natural cellulosic fibres (cotton, jute, sisal, coir, flax, hemp, abaca, ramie, etc.) and protein based fibres such as wool and silk. Excluded here are mineral fibres such as asbestos that occur naturally but are not bio-based. Asbestos containing products are not considered sustainable due to the well known health risk, that resulted in prohibition of its use in many countries. On the other hand there are manmade cellulose fibres (e.g. viscose-rayon and cellulose acetate) that are produced with chemical procedures from pulped wood or other sources (cotton, bamboo). Similarly, regenerated (soybean) protein, polymer fibre (bio-polyester, PHA, PLA) and chitosan fibre are examples of semi-synthetic products that are based on renewable resources. In this paper also the use of fibres in food industries is excluded, where in recent years these are frequently promoted as dietary fibres or as supplements for health products.

VALUE ADDITION IN FIBRE CONVERSION

Practically everywhere and in all countries natural fibres are produced and used to manufacture a wide range of traditional and novel products from textiles, ropes and nets, brushes, carpets and mats, mattresses to paper and board materials. The long fibres are transformed to threads or yarns that are used to join, connect or attach and to form bonds, networks or weaves.

The fibre and textiles industries are among the most labour-intensive sectors and therefore stimulate the industrialisation in cheap labour countries. Textiles production is often a major economic output for these countries. However, in many of the less developed countries the fibre and textile sectors are still poorly developed, but offer perspective for socio-economic development. This development should be sustainable and therefore not at the expense of the environment or exploiting workers. In the value addition chain of fibre crop production and supply to markets various environmental impacts can be distinguished. The impact factor on the environment is related to the production volumes of fibre products and the size of the end-use market.

Table 1 - Estimated global production volume averages of different natural fibres (in million metric tons per year average over the recent years).

	Mill. tonnes	Main producer countries
Cotton	25	China, USA, India, Pakistan
Kapok	0.03	Indonesia
Jute	2.5	India, Bangladesh
Kenaf	0.45	China, India, Thailand
Flax	0.50	China, France, Belgium, Belarus, Ukraine
Hemp	0.10	China [1]
Ramie	0.15	China
Abaca	0.10	Philippines, Equador
Sisal	0.30	Brazil, China, Tanzania, Kenya
Henequen	0.03	Mexico
Coir	0.45	India, Sri Lanka
Wool	2.2	Australia, China, New Zealand
Silk	0.10	China, India
Manmade cellulosic fibres	3.3	

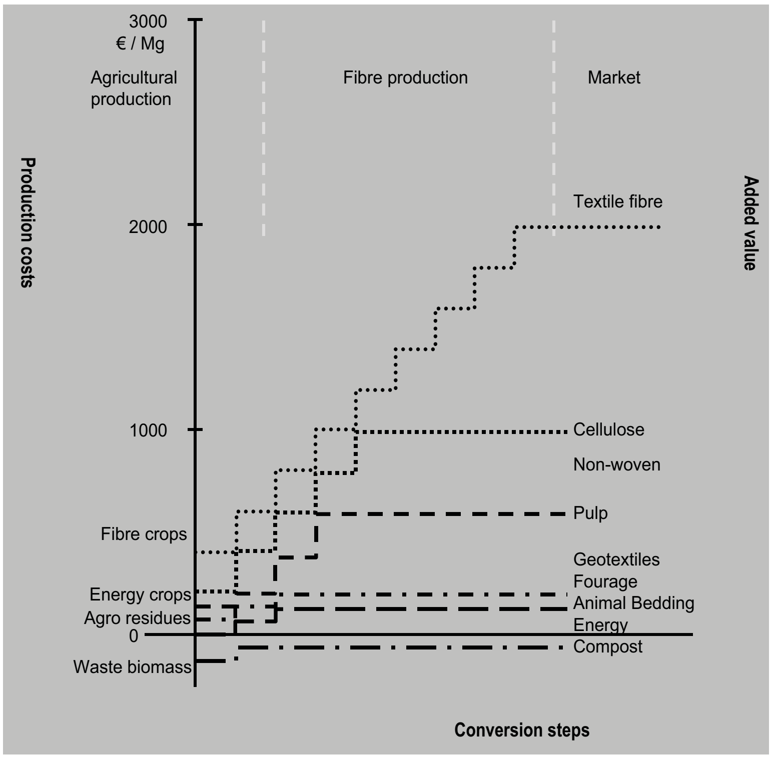
[1] China has announced to substantially increase the hemp production for textiles in the coming years to 1.5 million tonnes of fibre per year

Cotton is by far the largest fibre crop globally and is reaching almost 25 million tons production per annum (Table 1), accounting for almost 40% of the total textile fibre market. It is grown in many countries, but the majority of production is coming from China, USA, India, and Pakistan (see FAO statistics; ICAC; UNCTAD, ITC, WTO). Many sub-Saharan countries produce substantial quantities of cotton, but lack the local infrastructure and industry to produce quality export textiles for higher value addition. The global cotton fibre demand has shown a growth rate of more than 5% in the recent years, in line with the manmade fibre market expansion.

Other industrial natural fibres are produced in substantially smaller volumes, all together not exceeding 6 million tons production. These production volumes have stagnated in the last decades and these fibres are only supplying a few percents of the textile fibre market (2-3%) (FAO statistics).

Trade markets and exports of most of the natural fibres (Sisal and Henequen, Jute and Kenaf, Flax and Hemp) have seen a decline in the past decades, which is often attributed to introduction of cheaper synthetic substitutes. The market for jute bags for transport of agricultural products, for example, has seen dramatic decline, also due to increased

Fig. 1 - The relation between value addition and conversion steps in the fibre chain



container shipments. Agricultural twine and ropes is still one of the largest markets for especially sisal, while the highest fibre grades are used for manufacturing of rugs and home furnishing. Current innovation on the markets for natural fibre containing (composite) products has widened the scope of its use and that should go parallel with agro-industrial development. Then it has the potential to become a major sustainable bio-economic commodity.

The economic value of the fibre crop depends on its end-use market and costs of production. Fine and long fibres that can be spun into high counts of yarns are most appreciated and valued. On the other hand homogeneity is prerequisite to efficient processing and high quality end-products. Lower quality shorter or coarser fibres are converted into nonwoven products, paper pulp or other materials. The lowest value of fibres is when it is left in the field as mulch to compost. The value of the end-product is not always reflected in the benefits for the agricultural production, however. In the production chain from farm to customer many steps are taken (Fig. 1) and quality improvement is attained at the cost of substantial losses. By-products, residues and wastes commonly are not contributing to the value addition. On the contrary, these may cause environmental pollution or add to costs for disposal.

The environmental impact of natural fibres accordingly also relies on how by-product management is organized. In principle renewable resources will be fully bio-convertible and may be reutilised as source for carbon in the form of carbohydrates (sugars), lignin or protein (nitrogen) and minerals. Often agricultural production utilises only a small part of the total fixed carbon in the biomass produced or harvested. These wastes can be utilised far better. For example, only 2-4% of the harvested biomass of sisal is converted to economic value. The remains from the leaf contains short fibres and soluble sugars that are

Table 2 - Natural fibre major end-markets and by-products for value addition

Crop	Fibre Market	By-Product
Cotton	Textile fabric: apparel (60%)	Linter, cottonseed
	Home furnishing, upholstery	Stalks
	Non-wovens	
	Specialty paper	
	Cellulose	
	Medical and hygienic supplies	
	(Hydrophilic absorbents)	
Kapok	Pillow, mattress	Seeds, wood
Jute and Kenaf	Hessian, sacking	Stalks (sticks)
	Carpet backing	
Ramie	Textile fabric	Leaves, stem
Flax & Hemp	Textile fabric	Seeds, shives
	Composites	
	Non-woven, insulation mats	
	Specialist paper	
Abaca	Speciality paper, tea bags	Leaves, juice
Sisal & henequen	Twine and ropes	Short fibre, juice, poles, stem
Coir	Twine, ropes, carpets, brushes, mattress	Copra, water, shell, pith
	geotextiles, horticultural products	Wood, leaves
Wool	Knitted wear	Lamb meat, cheese
Silk	Fine garments	Worms, cocoons
	Veils and handkerchiefs	Fruits, wood

now commonly discharged in the environment. Other plant parts (poles and stems) are left in the field or burned. Recently, studies have been initiated that are aiming at zero emission models for the sisal industries and to use this waste biomass for ethanol fermentation purposes or production of biogas. Additional income from carbon trade (CDM) promotes (foreign) investments in local environmental and socio-economic improvements.

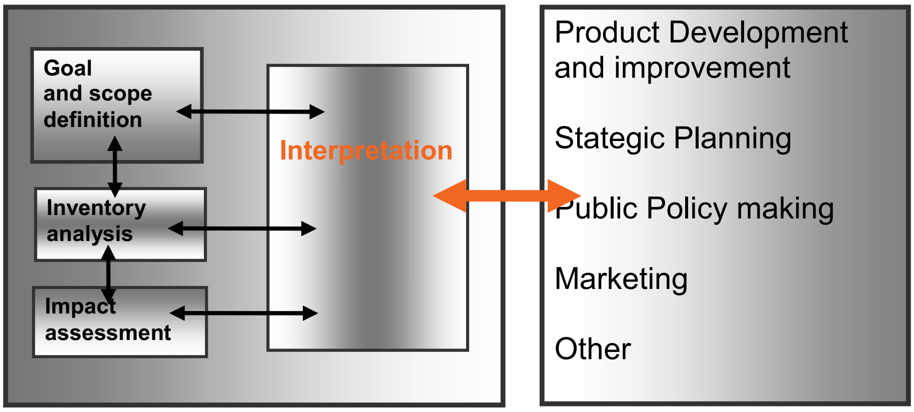
In bast fibre crops like flax, hemp and jute the yield of waste biomass per ha is relatively low. Approximately ⅓ of the stem dry weight is the appreciated long fibre. The woody parts (shives, hurts, stick) may be applied as light weight construction materials or burnt as (cooking) fuel. During the transformation from straw to fabric yield losses are considerable (Fig. 3). Different grades of tow and short fibres are released during the scutching and hackling processes that are better suitable for staple fibre spinning and rope making, for non-wovens and fibre composites and in non-wood specialty paper pulp production.

Many fibre crops also yield valuable oil seeds as by-products (cotton, kapok, linseed, hemp), and many oilseed crops yield fibrous residues. For example coir is considered a by-product from the coconut oil and copra production. Also the wool market may not be the main value to the sheep farming.

Life Cycle Assessment (LCA)

Comparison of the environmental impact of processes and products requires quantitative tools as criteria for the selection of the most sustainable option. Life Cycle Assessment (LCA) of products and processes is such method that was developed in the early 1980s. The environmental impact and the ecological implications of the entire life cycle of a

Fig 2 - LCA quantitative environmental impact framework



product are systematically classified and quantified from primary raw material production to processing and to final product disposal. LCA methodologies are composed of five stages (Fig. 2) :

- **Goal definition** establishing the aim and scope of the study and defining the function, as well as the functional unit of the product under examination.
- **Inventory** formulation that comprises of the analysis and listing of polluting emissions, the consumption of resources and energy per functional unit and the determination of the environmental intervention.
- **Classification** that includes the categorisation of the environmental interventions in a number of environmental classes and the formulation of environmental profiles for each class that often can be reflected in numerical values.
- **Interpretation** that comprises of the analysis of the results and the estimation of the related uncertainties.

The methodology for impact assessment is widely accepted and ISO standards have been established to compare and quantify the various weighing factors. The assessment consists of weighing the classes to integrate the environmental profiles such as effects on greenhouse gas emission, ozone depletion, acidification or eutrophication. It is however unrealistic to desire unification into one environmental impact number for widely diverse ecological and economical effects.

Difficulties in defining the system limits and in the collection of data, as well as measurement errors may hinder the conduct of LCA and result to misinterpretation of the environmental impacts. Careful objective inventory analysis (Fig. 2) of the various impact weighing factors and inventories of components can be made, but weighing against competing economic products is always at stake. The goal and scope of the LCA may affect the outcome to a certain extend. The goal can be either for product development and improvement, strategic planning, or public policy making, marketing or other. In advance definition of criteria and the weighing factors for emissions and consumption of resources is essential for determination of eco-indicators.

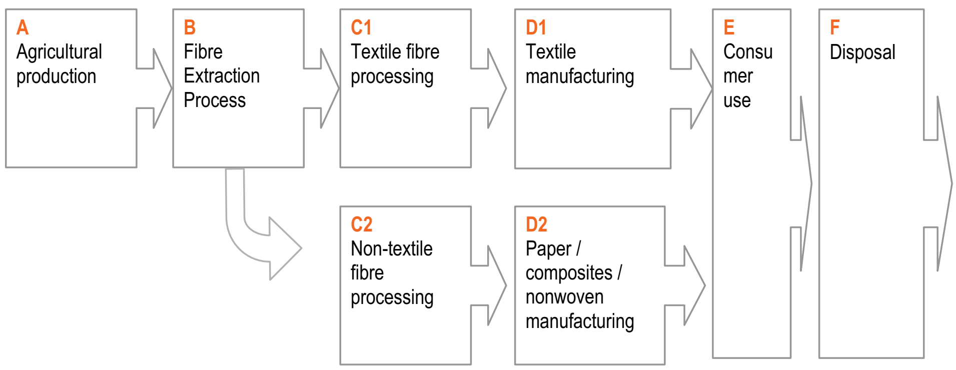
The ecological footprint is another well known method to compare and express the impact on the environment (Rees and Wackernagel 1994). The footprint is expressed in land area required per person to maintain his life style (including food, energy, water, travel, housing clothing etc.). To fulfil all the human needs, it is estimated that an area of 0.01 à 0.02 km^2

per person is required. The difference per capita of average footprint is strikingly different per country and directly linked to the consumption pattern and economic development. According to WWF and other NGO's the human footprint is approaching or even exceeding the available supply of natural resources or the planet's biocapacity. The increasing public awareness and concern about global warming and its consequences is now receiving broad political support. Many governments take measures to stimulate sustainable development and promote better use of available resources. One example of such a new approach towards the use of resources is the "cradle to cradle" (C2C) philosophy. A lot of positive response has been created by the C2C concepts of McDonough and Braungart, that are strongly focussed on the better design of products and full reuse of materials after disposal. Eco-effective design of products requires reuse of waste to make new products. The suggestion is made that limitless economic growth can be obtained when the resources are properly reused (without quality loss). This is disputable because the costs of recycling and upgrading are not taken into account. When the system boundaries are taken too wide – like critical observers recognise in the C2C approach – more uncertainties are created and room is left for discussions about measures to be taken for necessary ecological improvement. However, the moment seems right for ecological improvements that can be shared under this C2C umbrella. It inspires at least many governments and industries to rethink and to find alternatives for the way we make things. Our waste becomes the food for the next generations in everlasting consumer cycles?

Fibre quality chain

Determination of the LCA framework includes the inventory environmental impact of the various stages of the production chain. In the next paragraphs the environmental and sustainability issues that play a role in the different stages (Fig 3 **A-F**) of natural fibre production and use are discussed. These are including the input – output of energy or chemicals and a total mass balance of main product, by-products or residues and wastes. The production chain for fibre crops can be divided into three main links: agricultural production – fibre processing – and utilisation (Fig. 3).

Fig 3 - Agro-industrial chains of fibre crop production, processing and application



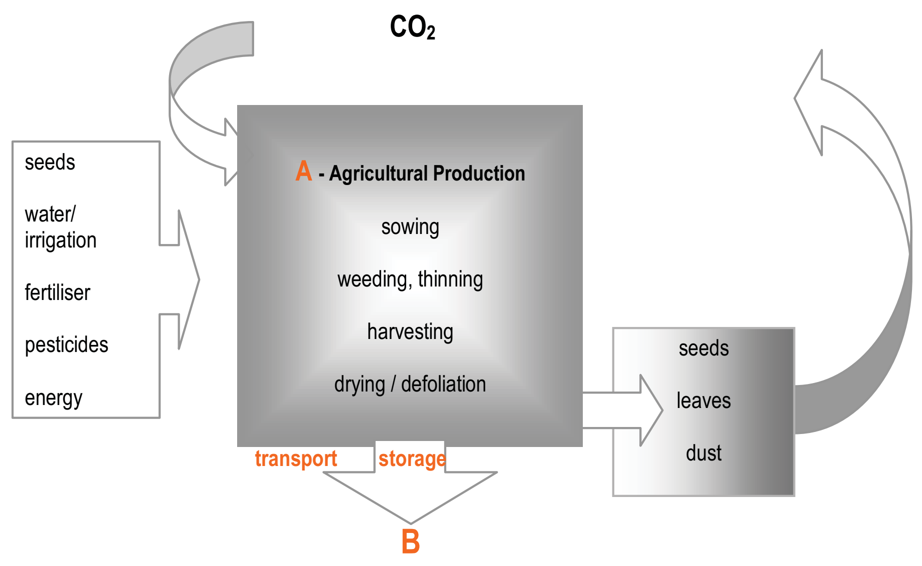
A - Agricultural Production

Breeding cultivation	Genetics for yield and quality improvement
Cultivation	Agronomy: soil, climate, weed, disease and pest control, fertilizers
Harvest/storage	Moment of harvest, mechanization, storage conditions, transport and handling

Since primary production is paid for quantity rather than quality, the breeding is often focussed on yield improvement and disease resistance. Concerns about the safety of genetically modified organisms or GMO-crops has resulted in fierce political discussions. The commercialisation of Bt cotton attracted reactions from environmentalists, although its use claims substantial reduction in the need for polluting pesticides. Their objections against GMO are the loss of biodiversity and uncertainty of risks of spreading potential harmful genes in the ecosystem.

Growing of crops results in the fixation in biomass of atmospheric CO_2 through photosynthesis and has therefore in principle a positive effect on the CO_2 balance. In the primary cultivation of fibre crops (Fig 4) the input of fertilizers, and agrochemicals for crop protection and disease control are well known factors that negatively contribute to the overall picture of the ecological friendliness of crop production. In addition the degree of mechanisation of soil preparation, sowing, weeding and harvesting adds substantially to the impact, due to the fossil fuel consumption. Several studies have calculated these in detail for especially energy crop production. For some fibre crops these calculations are made and compared with products such as synthetic alternatives. The production of fibre crops has varying impact on the environment, as far as the requirements for fertiliser and pesticides and energy are concerned. In general, the fibre crops under examination are found to have moderate requirements for fertiliser and crop protection chemicals, whilst energy requirements can be thought of as very small due to the extensive farm structure and the relative importance of labour in traditional farming systems. Consequently, the production of fibre crops has a limited impact on the environment.

Fig 4 A - Agricultural production inputs and outputs



B C D - Fibre Processing

Fibre extraction	Ginning/retting, braking, decortication, degumming
Fibre preparation	Cleaning, hackling, carding, refining, extrusion, steam explosion, chemical/biochemical treatments, etc

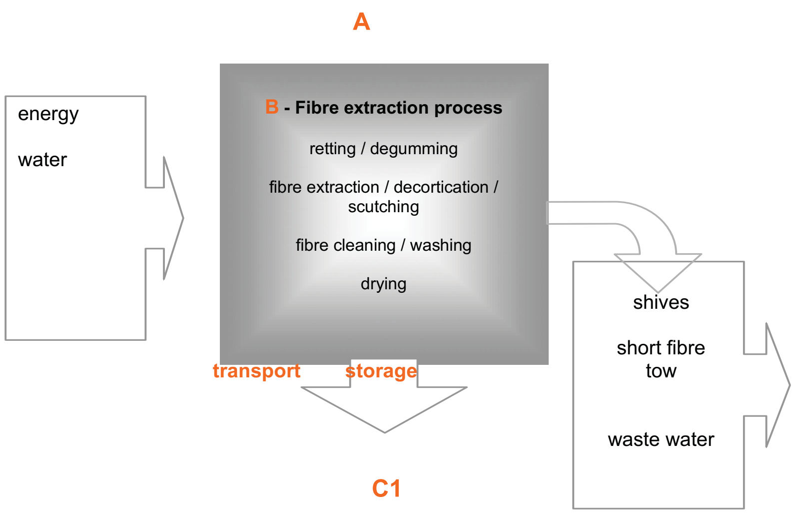
In the complex sequence (Fig.3) of fibre extraction **B** and manufacturing of half-products **C** and conversion to trade ware **D** different numbers of steps are required for each end-product with input of machines, energy and other resources or processing aids such as water, chemicals (dyes, surfactants, fire retardants or other additives), microorganisms, or enzymes. These are potential sources of pollutants of the environment when ignorant management and irresponsible disposal takes place. The fibre extraction process **B** consumes fossil energy and water, generates biomass waste and contaminates process water, thus presenting a considerable risk of pollution of surface waters, when no measures are taken for waste water treatment. Utilisation of residues and waste for generation of energy, or other value added outlets substantially enhances the overall ecological performance of a fibre crop.

Restricted quantitative information on input and output costs is available from industrial fibre production chains. Small holder industries often cannot afford to invest in waste treatment or are even still unconscious about the harm it may cause on the long run. For the large industries, taking the lead in responsible entrepreneurship and consequently a keen interest in improved ecological performance and sustainable supplies of bio-based resources, up-stream quality control includes investment in the ecological performance of their suppliers. Obsolete methods of fibre extraction and fibre processing not only can be a source for pollution, but also affect labour conditions of workers.

In general, comparative studies on the production phase of fibre crops with synthetic products, or glass fibres, indicate that fibre crops provide environmental benefits in terms of reduced CO_2 and greenhouse gas emission levels and consumption of fossil energy.

Most common natural fibre textiles for clothing are produced from cotton or to a lesser extend from other fibres such as flax linen yarns, silk and wool. The sequence of fibre preparation for spinning and weaving and finishing comprises a number of processes that

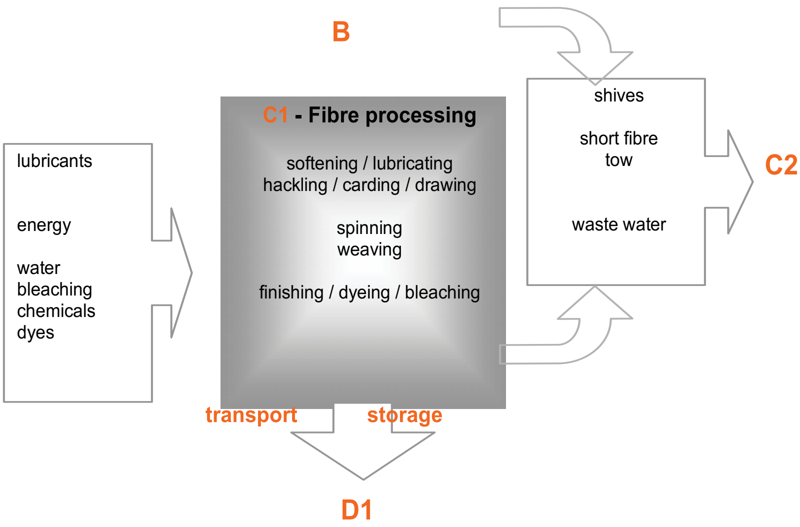
Fig 5 - **B** - Fibre extraction inputs and outputs



C-1/D-1 - Textile production

Fibre processing	Spinning, weaving, dyeing, printing, finishing

Fig 6 - C1 - Textile fibre processing inputs and outputs



require energy and chemical additives, and process water. Textiles nowadays are often produced from blended yarns (with synthetic or other natural yarns) to improve the wear comfort or appearance of the end product (gloss, elasticity). Traditional hemp textiles were too coarse for apparel, but improved techniques allow production of lighter and softer texture and enhance its utility. Similarly the jute fibre applications are far extended beyond the traditional jute bags used for packing of agricultural products.

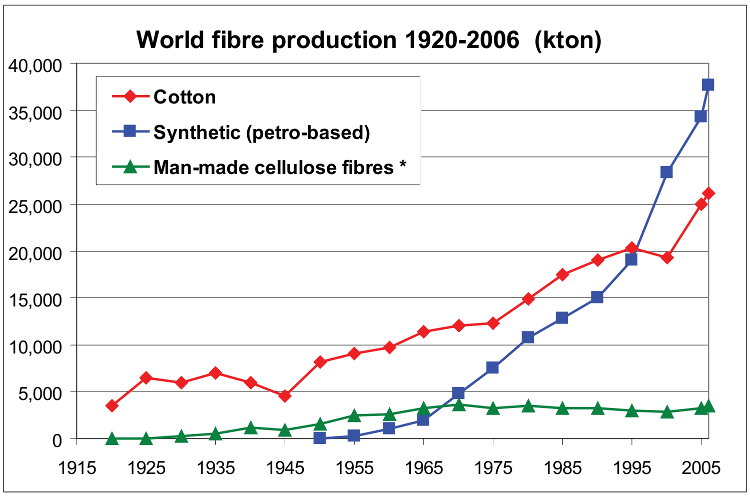
World fibre production volumes for textiles is strongly increasing (ever since mid 20th century with upcoming competition from petrochemical based fibres) for both cotton and manmade fibres (Fig.7). The textile markets for regenerated cellulose and cellulose derivatives remain at a modest levels. The classical process of manufacturing viscose may use different sources of cellulose derived from wood pulp, cotton linters or bamboo pulp. The heavy pollution this process caused in the past has been eliminated almost completely, due to chemical recovery. But energy and chemical consumption still are considerable.

Environmental concerns have successfully banned the most toxic chemicals that were in use in the past for textile dyeing and bleaching and new standards have been designed for risk avoidance and prevention along the entire textile manufacturing chain.

The natural fibres that are used for non-textile applications can be grown on purpose for this market (e.g. Abaca for specialty paper) or the cheaper lower quality fibres unsuitable for textile processing may find a niche outlet in paper making, composites or nonwoven manufacturing. Many novel end-uses for cellulosic fibres have been identified and many have been demonstrated to be technically feasible or have already entered the market.

The lower qualities of fibre (tow, straw), which are produced as residue from agro-industrial production have to compete with highly efficiently organized and therefore relatively cheap wood fibre on the market for paper and pulp, fibre board and composites. Both hard- and softwood fibres are utilised on large scales for refining and pulping. Only about 7% of the world's virgin cellulose pulp is made from non-wood sources (mainly straw, bagasse, and bamboo) (Table 3). In the EU, US and Canada paper industries practically only wood pulp is currently used.

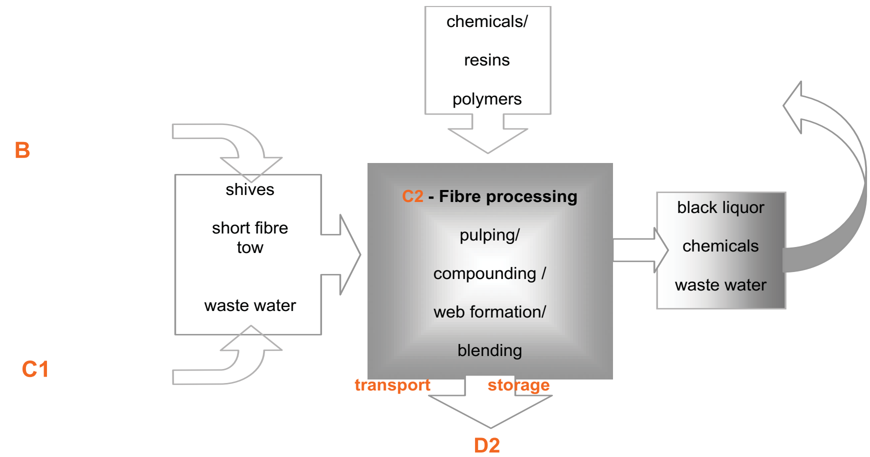
Fig 7. – World textile fibre production volumes over the last century (source IVE 2007)



Compared to wood based pulping natural fibre pulping processes for the production of paper, board and cellulosic fibre products is, in general, ecologically advantageous due to the lower energy and chemicals requirements. However, chemical recovery for small scale pulping is economically unattractive and, therefore, pulping of fibre crops, such as bamboo, jute, kenaf, abaca and hemp often causes severe pollution requiring integrated waste water control.

The major fibre sources for non-wood pulping are cotton linter, rice and wheat straws and bamboo.

Fig 8 - C2 - Non-textile fibre processing inputs and outputs



C-2/D-2 - Non-textile end-use

Fibre processing	Pulping, refining, compounding, moulding

Table 3 - Global non-wood paper pulp production capacity (FAO)

Country	Capacity (million tonnes)	% of total
China	15.2	71
India	2.0	9
Mexico	0.3	1
Peru	0.3	1
Philippines	0.3	1
Indonesia	0.3	1
USA	0.2	1
Thailand	0.2	1
Colombia	0.2	1
Brazil	0.2	1
10- Country Total	19.2	90
Total World	21.3	100 (<7% total pulp)

- Cotton linter
  Abaca
  Flax
  Hemp
  Kenaf
  → Banknote and security paper, tea bags, filters
  Sausage casing
  Cigarette paper
  Electrolyte condensor paper

- Straw
- Sugar cane bagasse
- Bamboo

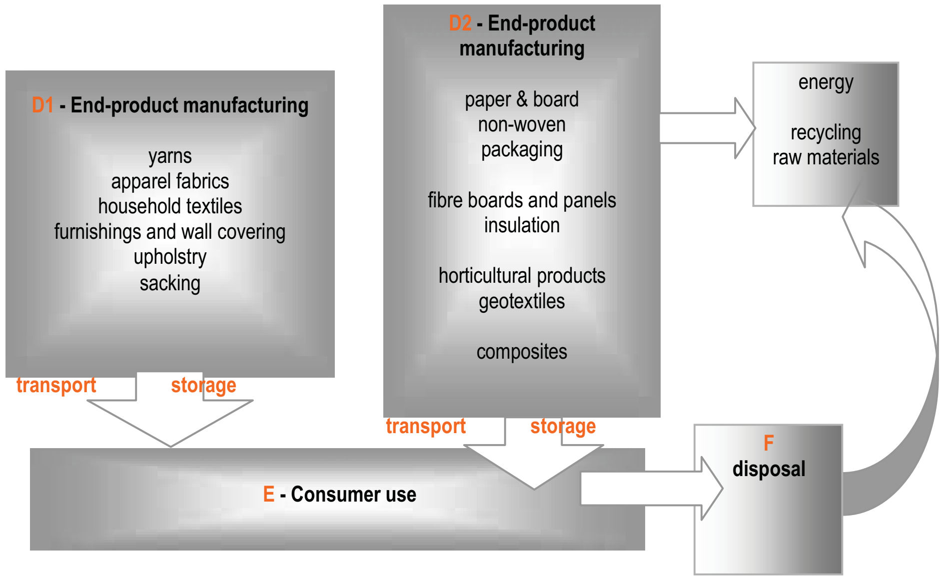
→ Paper board / wrapping paper

Other non-textile markets for natural fibres (table 2) are found in fibre composites, where substitution of mineral fibres (asbestos, glass fibre) has been demonstrated to be feasible. In fibre cement and fibre reinforced polymer composites or fibre boards numerous products can be fabricated for building or automotive applications. Coir and jute fibres have demonstrated their value in biodegradable geotextiles for erosion control and ecological sustainable solutions in civil engineering.

The low-end market outlet for fibrous biomass is found in energy production (Fig. 1). Its heating value is the base-line value for economic conversion. Due to the emerging bio-based economy worldwide governmental promotion of renewable energy and biomass conversion plants is targeting for a substantial contribution to the energy production over the next 10 years. The 2nd generation bio-fuels based on conversion of lignocellulose feedstock into ethanol, pyrolysis oil or biogass is investigated all over. Since biomass utilisation for energy production is still expensive, compared to fossil energy sources, the so called biorefinery principle is considered. Combined fibre extraction and energy production may increase the revenues.

For many of the products made from natural fibres a substantial contribution to the complete life cycle (or cradle to grave) impact is attributed to the utilisation and disposal phases. Comparison with non-renewable alternatives is then relevant. Cotton requires less fossil resources in its production phase (e.g. energy, fertilizer, pesticides) than synthetic polyester but higher demand for water. No dramatic differences of the environmental impacts in textile processing (dyeing and bleaching) can be observed, but in general

Fig 9 - D E F - End products manufacturing and use inputs and outputs



E F - Utilisation

Use	Performance
Disposal	Reuse and recycling, incineration / degradation

synthetic or blended fabrics show a longer functional life time. On the other hand in the utilisation phase the lower energy requirement in laundering for synthetic textiles can be an argument. The consumer's perception of wear comfort and garment appearance often are more decisive for purchasing. The environmental costs of an attractive product commonly then are of lower priority.

The use of natural fibre based geotextiles in civil engineering offers large environmental advantages by the fact that these are fully biodegradable and no synthetic polymers remain in the soil after its functional lifetime. Similarly, in agriculture and horticulture the use of natural fibre based twine or nonwoven mats, planting pots etc., do not require removal since they are compostable, which improves even the soil structure.

In the automotive industry the use of cellulosic fibres as renewable raw material in fibre reinforced composite materials has received much attention as "green" development and is showing much promise. Since its introduction a decade ago the use of natural fibres in automotives has shown increasing trends. Among those, flax and hemp non-woven find a growing outlet in compression moulded trim panels and dashboards. The natural fibre reinforced injection moulded composite parts show less demands on the fibre processing and handling (as compared to textile fibre production). The biggest LCA advantage over glass fibre reinforced composites is the weight reduction resulting in lower fuel consumption in the use phase. Other advantages are the lower wear of equipment in the production phase and easier end-of-life recycling by incineration.

Another potential large market for ligno-cellulosic materials is found in an increased interest for renewable materials in ecological building and construction applications. For example, it has been demonstrated that high performance / high quality fibre boards can be manufactured from the whole fibrous coconut husk without the use of any chemical additive. The global demand for building materials and timber is ever increasing and with rising prices of wood the market for sustainable timber substitutes seems bright. Coconuts are abundantly available in the poorest regions and their husks now often discarded because of lack of economic value. Manufacturing of ecologically and (bio-)economically sustainable materials from this waste could create many jobs and offer new perspective for local industrial development.

The introduction of novel products on this scattered and conservative market of building materials is difficult. This is due to complex building regulations and standardisation in the different EU member states, combined with traditions and different legislation on the use of building materials. Implementation of alternative renewable building products at large scale involves substantial commercial challenges that should be the driving force behind development of the production chain. This can only be achieved when the qualitative and quantitative aspects have been defined in detail for each specific end-use. It should be substantiated that especially in the case of building materials, the ecological advantages should combine with better comfort, health and safety aspects (indoor climate), without premature degradation or excessive maintenance costs or the need for hazardous chemicals for preservation.

Research agenda

The present review of the environmental impact of natural fibre production and industrial applications highlights the need to comprehensively evaluate the environmental benefits that emanate from the use of fibres, as well as the possibility of utilising the existing research results for promoting natural fibres.

Firstly, numerous unexplored areas can be identified for research, such as in the case of building materials, where comparisons of LCAs need to be undertaken, taking into consideration the costs of maintenance and replacement in relation to the performance of the material. In other areas, as in the case of horticultural production inputs, where data on their contribution to the environment is not available, LCA could be used to promote fibre based products. Other fields of research may include improvement of the fibre and cellulose extraction process from fibre crops (sisal, abaca), underutilised crops (bamboo) and crop residues (straw, bagasse) and waste control, novel fibre production processes and applications and the production of natural binders (lignin) and coatings (wax) such as for the manufacturing of boards from coir husks.

Secondly, existing research results may be utilised in order to promote applications of natural fibres. For example, nursery products, such as biodegradable flower pots may consist of a promising area for growth, given the necessary promotion. More generally, the packaging sector, in view of the stringent EU regulations, may provide a niche market for natural fibres.

Discussion and conclusions

The politics for changing to a bio-based economy requires substitution of common raw materials, that are currently largely produced from fossil (petrochemical) or mineral resources, by products produced from renewable (plant and animal based) resources. On ecological grounds products like natural fibres should then be preferred that are based on short rotation photosynthetic CO2 fixation. Therefore, competitive products based on renewable resources need to be developed that have high quality, show excellent technical performance and harm the environment less than current products based on petrochemical materials.

Ecological impact assessments are complex and often use incomparable weighing factors. The impact of primary agricultural production of fibre crops on the total LCA varies strongly per crop and depends on levels of mechanisation and use of agro-chemicals. Overall ecological performance of a crop improves when residues and by-products are better utilised.

By-product utilisation and installation of waste water treatment systems (biorefinery, whole crop utilisation) substantially contributes to an enhanced sustainability of (fibre) crop production chains.

In the production phase the score of fibre crops on CO_2 and greenhouse gas emission levels, fossil energy consumption and resources is much better than for competing petrochemical products. The effects of technical modernisation of production systems on the total LCA of fibre products need to be balanced with economical competitiveness and social aspects of labour provision. Rural agro-industrial developments counteracts urbanisation.

The impact of synthetic resins, additives and polymers on the LCA is large in blended textiles or non-wovens and composite materials. In many cases also the utilisation and disposal phase contributes substantially to the overall impact. Quantified LCA's for the various application areas of fibre crops should lead to well-founded systems for eco-labeling and certification of the best practices.

The environment has become a major driver for industries and governments. The time seems right for eco-effective design as promoted in the 'cradle to cradle' (C2C) concept. This has evoked a lot of response from industries who are seeking more eco-efficient production and sustainable commerce. The growing competition for renewable resources for energy and products will also open new possibilities for exploitation in biorefineries of biomass from agro-industrial residues for production of energy, bio-gas and electricity, but also many other products like animal feed and organic soil improver, constructive building products and composite materials, or even textiles or pharmaceuticals. Natural fibres and their by-products will play a central role here. Natural fibres are a major renewable (CO_2 neutral) resource for bio-based economical developments.

The competing claims for biomass resources gives increasing concerns about food supply security, land use and effects on deforestation and rural development. Fibre crops compete with food crops for land, water and nutrients on profit base. When the crop value sustains the farmers according to fair trade principles this does not cause problems. But, there is need for development of technologies to suit the scales of production possible in developing countries and LDC's. R&D strategic research agendas need to be implemented that make technology transfer possible. Promising tools and methods need to be demonstrated in practical situations.

There is not one strategy to achieve the various targets for enhanced use of natural fibres. Each individual crop and product demands a systematic approach. Sophisticated combination of resources and processes are leading to sustainable energy supplies and defined value added products.

Certification of the sustainability of the production chains for biomass energy and products is needed. International "commodification" of the multipurpose biomass for energy production and non-food applications requires international attention with respect to competing claims for land use and biodiversity issues. Responsibility for sustainable imports and exports of bio-based goods lies with the governments.

The ecological impact of a product is not yet an important marketing issue. As long as the use of non-renewable products is not restricted by legislation or extreme costs fibre crops will be applied in the market niche where the best price / performance can be found. The specific performance of a product and cost reduction are still the major drives for a competitive market introduction. The appeal of natural fibre products should primarily be its quality.