Circularity in DRE Livelihood Value Chains

Understanding the role of circularity in agricultural value chains and the role of DRE productive use solutions

SELCO Foundation

Contents

This document **unpacks what circularity could mean in the context of agricultural and allied value chains in India**, and the **role machines powered by decentralised renewable energy (DRE) can play** to aid it. It considers various crops, residues, by-products, nutrients and water, and the energy that can be recovered from them.

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What Circularity Means in Agriculture

Circularity means keeping materials, nutrients, water and energy in use for as long as possible, instead of losing them as waste.

It can take place at all levels: a farm, a value chain or a whole economy. There is no single agreed definition of the circular economy, and reviews of the research have found well over a hundred definitions. Most describe it as a mix of reducing, reusing and recycling. Circularity is an old practice in Indian farming. Dung, crop residues and water have long been reused on small farms and to make value added products.

A Timeline of Circularity in Agriculture and Industry

~1000

Surapala's *Vrikshayurveda* describes kunapajala, a liquid manure made from animal waste.

1762

Alappuzha port in Travancore is set up mainly to export coir mats and yarn spun from coconut husk. By the 1860s, coir yarn makes up about 17% of Travancore's exports.

1911

F.H. King's *Farmers of Forty Centuries* describes how farmers in China, Korea and Japan return almost every kind of organic waste to the soil.

1924–40

Albert Howard builds on traditional Indian composting to develop the Indore method, later set out in *An Agricultural Testament* (1940).

1989

Frosch and Gallopoulos set out industrial ecology: industries that use each other's waste as inputs.

1990

Pearce and Turner use the term "circular economy" in environmental economics.

In farming, circularity means putting every part of what is grown to its best use.

A farm produces much more than its main crop. Paddy leaves straw, husk and bran. A dairy animal gives milk, but also dung and urine. Fruit leaves peel, seeds and leaves. Circular agriculture asks what the best use is for each of these materials, so that as little as possible is lost. Circularity in agriculture is discussed under several names. Three are common in India: agroecology, integrated farming systems and waste to wealth.

Agroecology

Agroecology is an approach to farming that works with natural processes, and draws on both science and farmers' own knowledge. The Food and Agriculture Organization (FAO) sets out ten elements of agroecology. Recycling is one of them: nutrients, biomass and water are reused within the farm and the landscape, which lowers costs and reduces dependence on bought inputs.

Integrated Farming Systems

An integrated farming system keeps crops, animals and sometimes fish, trees or bees on one farm, and links them so that the waste from one part becomes an input for another. Crop residues feed the animals, dung goes to compost or biogas, and pond water irrigates crops. Because the farm uses its own by-products, it needs fewer inputs from outside.

Waste to Wealth

Waste to wealth is the term used in Indian policy for turning organic and other waste into energy, manure or income. The best-known scheme is GOBARdhan, launched in 2018, which supports biogas plants at household, community, cluster and commercial scale.

A popular framework comes from **Wageningen University and Research** in the Netherlands (de Boer and van Ittersum, 2018). It rests on three principles:

Land and crops should be used to **feed people first.**

Crop residues, processing by-products and food waste are returned to the soil, fed to animals, or used for energy and materials.

Animals turn grass and by-products that people cannot eat into milk, eggs, meat and manure.

The order of priority of circular practices in agriculture

From these principles comes an order of priority of use. It ranks the uses of crop residues, by-products and food waste in descending order of the value they keep. The higher a use sits in the order, the more valuable it is. The order is a general guide. **The best use of a residue in a given place also depends on local conditions, such as how much of it is available, what it is already used for, the health of the soil, and the water and land available.**

1. **Prevent loss**
   Reduce spoilage and waste in the first place, through better storage, drying, cooling and timely processing.
2. **Use as human food**
   Where food is surplus or a by-product is edible, keep it in the human food chain, for example by drying fruit or making flour from seeds.
3. **Return to the soil**
   Use crop residues, compost and slurry to keep soils healthy. Healthy soil is the base of all farming.
4. **Feed animals**
   Give animals what people cannot eat, such as straw, bran and oil cake, kept dry and free of mould. Their dung returns to the soil.
5. **Recover energy and materials**
   Turn what is left into biogas, briquettes, fibre, leaf plates or board, so that it still earns or saves money.
6. **Dispose of safely**
   Dispose of only what cannot be used at all, without open burning or polluting water.

This priority order is adapted from de Boer and van Ittersum (2018).

Judging Productivity in Circular Agriculture and Allied Activities

A circular practice is worth promoting to farmers and producers when it leaves them better off economically or socially, and not only when it closes a loop and meets ecological criteria.

Circular productivity is the extra value a producer gets from land, labour, water, energy or money by using residues, by-products and energy that would otherwise be lost. Value can be measured as surplus food, energy, inputs no longer bought, time saved, and gains in soil and water over the years.

Six criteria have been developed from both the order of priority and circular productivity, to judge how useful a practice is to the people who adopt it.

Income Gained

The practice adds to or protects the producer's cash income.

Inputs Saved

It replaces what the producer would otherwise buy, such as fertiliser, feed or fuel.

Time Saved

It saves labour and reduces drudgery, especially for women.

Soil Restored

It improves soil health or water over several seasons.

Risk Reduced

It reduces exposure to price, weather or input shocks.

Cost Effective

It is feasible to set up and run, or pays back quickly.

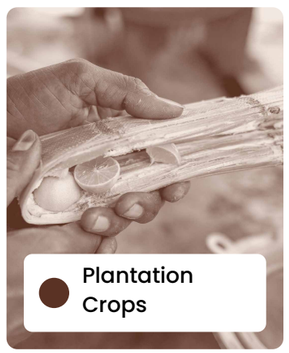
Prioritised Value Chains

Sixteen value chains have been analysed to see which circular practices, and which DRE solutions, could be introduced in them. They span animal husbandry, cereals and oilseeds, horticulture, plantation crops, and forest and fibre products.

The value chains were prioritised based on SELCO Foundation's work, and are not ranked against each other. Their by-products are already reused by smallholder farmers, often in traditional ways. Even so, much is still burnt, dumped or left to rot, and fresh produce that goes unsold when markets fall spoils along the way. The diagram lists each value chain with the main by-products it leaves.









Photos: SELCO Foundation



DRE Opportunities

Based on the order of priority, the value chain analysis has identified six types of opportunity, each backed by evidence of use in India and elsewhere. Each type has common DRE solutions that can be used across value chains, and each practice meets the criteria for judging circular productivity.

A Processing and Storage to Prevent Loss of Produce

Loss prevention sits at the top of the order of priority, because produce that is saved needs no additional land or water. Solar dryers, cold rooms and milk chillers keep produce safe from rain, humidity and heat at the farm, where sun drying fails and grid power is unreliable.

Applicable Value Chains

Pineapple, mushroom, vegetables, jackfruit, banana and milk, along with cereals, coffee, coconut and areca nut.

Suitable Machines using DRE

Solar cabinet and bubble dryers, cold rooms, milk chillers, hermetic bags and ventilated stores.

B Decentralised Processing at Local Levels

Processing near the farm keeps by-products close to the animals and soils that can use them, and keeps more value in the village. Solar or hybrid power makes small mills and expellers viable in villages where grid power is unreliable, at a lower running cost than diesel, so processing stays local.

Applicable Value Chains

Paddy, millets, maize, oilseeds, coconut, areca nut, jaggery, pineapple, jackfruit, coffee and eri silk.

Suitable Machines using DRE

Destoners, dehullers, mini rice mills, shellers, dehuskers, oil expellers, motorised ratts and food processing equipment.

C Turn Residues into a Second Product

Producing secondary products helps attach a monetary value to by-products and residues, so that they are collected and sold instead of burnt or dumped. A steady solar supply lets fibre, plate and briquette machines run full shifts where grid power is unreliable, and replaces costly diesel generators.

Applicable Value Chains

Banana and pineapple stems and leaves, areca, coconut, bamboo, paddy and coffee.

Suitable Machines using DRE

Fibre extractors, decorticators, plate and briquette presses, kilns, slicers, dryers and biomass kilns.

What DRE Adds to Circular Practices

Many circular practices, such as composting, feeding residues to animals and sun drying, have long been practised. What is often missing is energy at the right place and time. DRE supplies power and heat from solar, biogas and biomass where grid power is unreliable or diesel is expensive, so that drying, cooling and processing can happen at the farm, on time and at a lower running cost than diesel. Biogas and biomass fuel can also come from the residues themselves.

D Return Nutrients to the Soil

Healthy soil is the base of all farming, and returning nutrients cuts the fertiliser farmers have to buy in the long run. Biogas turns dung into cooking fuel while its nutrients stay in the slurry, and solar power runs shredders and slurry pumps where grid power is unreliable or diesel is expensive.

Applicable Value Chains

Dairy, mushroom, coffee, coconut and areca, sugarcane and banana trash, bamboo, maize and vegetables.

Suitable Machines using DRE

Biogas units, shredders, compost turners, slurry pumps, small straw choppers and portable kilns for biochar.

E Use Residues as Feed

Animals turn inedible by-products into milk, eggs and meat. Feed must be dry and free of mould, and toxic residues. Solar power runs chaff cutters and hydroponic fodder units where grid power is unreliable, and solar drying preserves residues for the lean season without burning fuel.

Applicable Value Chains

Millets, paddy, maize, oilseeds, coconut, pineapple, banana, jackfruit and eri silk.

Suitable Machines using DRE

Chaff cutters, silage choppers, dryers, pulverisers and hydroponic fodder units.

F Recover Energy Efficiently

Energy recovered from residues replaces diesel, firewood and LPG, and is the last useful step to achieve circularity before waste disposal. Biogas units, gasifiers and efficient furnaces recover energy from dung, husk, bagasse and other residues, replacing diesel, LPG and firewood.

Applicable Value Chains

Dairy, jaggery, paddy, coffee, vegetables, maize and oilseeds.

Suitable Machines using DRE

Biogas units, efficient furnaces, gasifiers and char-making stoves.

Animal Husbandry

Animals are central to circularity on the farm. Their dung and litter are used as manure and as a source of energy.



By-products and Waste Generated at Different Nodes of the Animal Husbandry Value Chain

Fodder and feed
Coarse residue left uneaten by cattle

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Housing and health
Dung, litter, droppings, feathers, wash water, spoilt medicines and vaccines

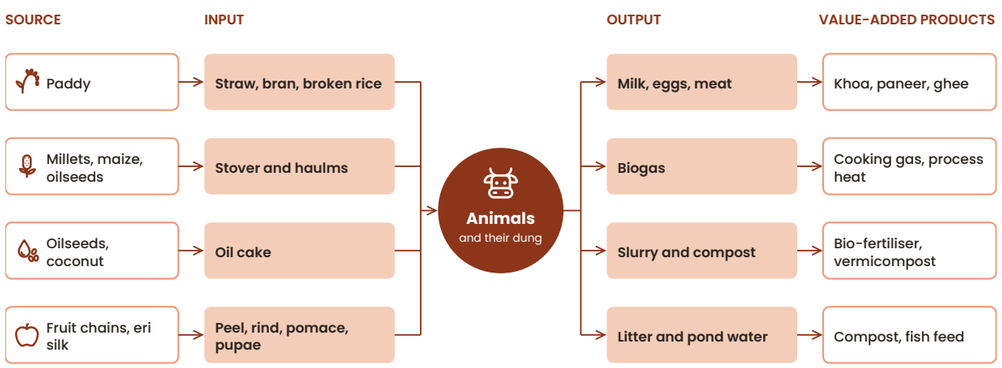
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Milking and collection
Hot water from chillers, spoilt milk

←

Milk processing
Whey, firewood and diesel burnt inefficiently

Diagram of Inputs and Outputs



DRE Opportunities for Circularity in Animal Husbandry

DRE OPPORTUNITY	CIRCULAR PRACTICE	DRE SOLUTIONS
A. Processing and Storage to Prevent Loss of Produce Income Gained Risk Reduced	Prevent milk losses through chilling, and loss of chicks through incubation.	**Can, instant and bulk milk chillers, vaccine storage units, egg incubators and brooder boxes**
B. Decentralised Processing at Local Levels Income Gained Inputs Saved Time Saved	Process milk into milk solids, butter, cheese or paneer locally, with by-products such as whey fed to animals.	**Khoa machines, butter churners**
C. Turn Residues into a Second Product Income Gained Soil Restored	Process slurry from biogas units, test it and sell it as branded organic manure.	**Drying and packaging unit, testing kits**
D. Return Nutrients to the Soil Inputs Saved Soil Restored Cost Effective	Compost dung, cow urine, poultry litter and biogas slurry, and apply it to farms.	**Biogas, slurry pump, shredder, vermibeds, bio-fermenter, sloped floor and urine tank in cattle sheds**
E. Use Residues as Feed Income Gained Inputs Saved Time Saved	Chop crop residues and grow fodder on the farm, so that less feed is bought or wasted.	**Chaff cutter, hydroponic fodder unit, azolla beds**
F. Recover Energy Efficiently Inputs Saved Time Saved	Use dung in household biodigesters to make gas for cooking and processing milk, and solar power for cattle shed work.	**Biodigesters, solar milking machine, water heater and fogger**

1.7 m³

of biogas can be generated a day from 5 cows, about 21 kg of LPG a month, plus 135 litres of slurry a day

~50%

of residential PM2.5 in India came from dung stoves used by under 10% of households (2020)

Value-Added Products from By-products and Waste



Photo: SuSanA Secretariat, CC BY 2.0

- **Biogas for cooking**
  From dung



Photo: Emmanuel Ssekaggo, CC BY-SA 4.0

- **Bio-slurry manure**
  From biogas slurry



Photo: Sonja Pauen, CC BY 2.0 DE

- **Paneer and khoa**
  From surplus milk

Examples of Circularity in Animal Husbandry



An integrated farm in coastal Karnataka

Kumta, Uttara Kannada

Nagaraj Naik farms under four acres, most of it leased. Dung from his cows and droppings from his chickens go into a biogas unit that supplies the household's cooking gas. The slurry is turned into vermicompost and returned to the fields, and Napier grass and azolla grown on the farm feed the animals. A solar-powered pulveriser lets him process his own produce and sell it under his own brand.



Photo: Down To Earth

A women-run manure cooperative

Zakariyapura, Anand, Gujarat

In Zakariyapura, 368 households run small biogas plants with support from the National Dairy Development Board. A women-run cooperative buys slurry from each household at ₹0.25 to ₹2 a litre, depending on quality, and sells it as branded organic manure. Households earn ₹1,500 to ₹2,500 a month from slurry and save ₹3,500 to ₹4,500 a month in all, and women spend much less time collecting firewood.



Photo: SNV

National Biogas Programme of Ethiopia

Ethiopia

Run by Ethiopia's Ministry of Water and Energy with SNV and co-funded by the European Union, the programme has installed more than 25,000 household biodigesters for farmers with at least four cattle, benefiting over 180,000 people. The bio-slurry fertilises about 140,000 hectares a year and can also be sold. Firewood use has fallen by about 100,000 tonnes a year, and women save an average of 1.43 hours of work a day.

Paddy

Paddy has three main residues: straw, husk and bran. Grain is also lost after harvest to floods and damp weather.



By-products and Waste Generated at Different Nodes of the Paddy Value Chain

Seed and growing

Seed is spoiled by humidity, and nutrients are washed out by waterlogging

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Harvest and threshing

Straw and stubble, burnt in some regions; grain lost to late rain

↓

Drying and storage

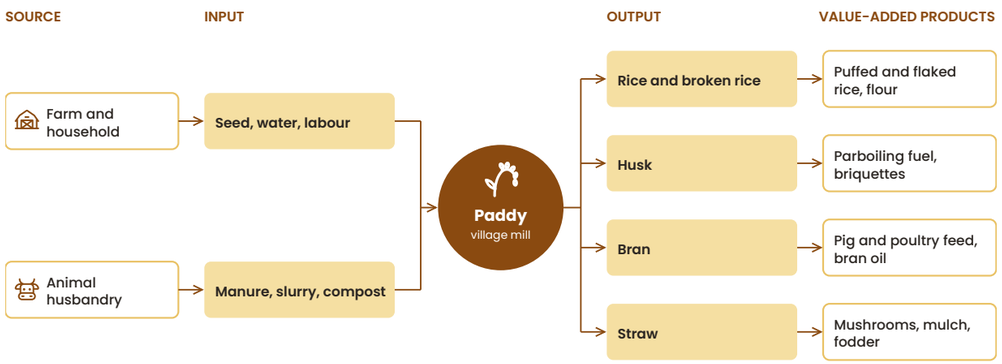
Grain spoiled by rain and humidity in open drying

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Parboiling and milling

Husk, bran and broken rice, unused in the absence of suitable users or markets

Diagram of Inputs and Outputs



DRE Opportunities for Circularity in Paddy

DRE OPPORTUNITY	CIRCULAR PRACTICE	DRE SOLUTIONS
A. Processing and Storage to Prevent Loss of Produce Income Gained Risk Reduced	Drying paddy and storing grain and seed so that floods and humidity do not spoil them.	**Solar bubble or biomass dryer, hermetic storage, solar freezer for seed, seed treatment drum**
B. Decentralised Processing at Local Levels Income Gained Time Saved	Milling paddy in the village, so that bran, husk and broken rice stay near local farms and animals.	**Precleaner, destoner, huller, polisher, grader, flour mill, puffed rice equipment**
C. Turn Residues into a Second Product Income Gained Soil Restored	Growing mushrooms on paddy straw, then composting the residues and applying it to the fields.	**Chaff cutter for substrate, steam or hot-water treatment, shredder for composting**
D. Return Nutrients to the Soil Soil Restored	Chopping straw and spreading it on the field instead of burning it.	**Small straw chopper or seeder sized for small farms, thresher with winnower**
E. Use Residues as Feed Income Gained Inputs Saved	Feeding bran and broken rice to pigs and poultry, and raising fish in the water of paddy fields.	**Village mill, channels and trenches for fish, links to animal husbandry**
F. Recover Energy Efficiently Inputs Saved Time Saved	Burning husk in efficient furnaces or gasifiers to heat parboiling and drying.	**Efficient parboiler, husk-fired furnace or gasifier with blower**

41.7 million tonnes

of surplus paddy straw a year in India, the largest single crop residue stream

~20%

of paddy by weight is husk, a fuel that can run mill engines through gasifiers and dry paddy

Value-Added Products from By-products and Waste



Photo: Kembangraps, CC BY-SA 4.0

- **Paddy straw mushrooms**
  From straw



Photo: Karel Bílek, CC BY-SA 4.0

- **Husk as kiln and boiler fuel**
  From husk



Photo: Dennis Sylvester Hurd, CC0

- **Rice bran oil**
  From bran

Examples of Circularity in Paddy



A solar rice mill that keeps husk separate

Nartap village, Nongpoh, Ri Bhoi, Meghalaya

Mr Ionis ran a diesel-powered rice mill in the village, which needed a fan to separate the husk. With SELCO Foundation and its ground partner MOSONiE, he set up an integrated unit for rice, bran and powdered husk. In the solar rice huller, the husk comes out separately, and some villagers take it to use as animal feed. He now buys one jar of diesel instead of three, and earns a profit of about ₹5,000 a month.



Photo: Takachar

Takachar

Northern India

Takachar makes a small, portable machine that attaches to a tractor and turns crop residues such as paddy straw into products like fuel and fertiliser on the farm itself. This gives farmers an alternative to burning straw in the field. The company reports that it cuts smoke emissions by up to 98%, and it won the Earthshot Prize in 2021.



Photo: CGIAR

RiceEco: rice straw to mushrooms and compost

Vietnam and Cambodia, led by IRRI

The RiceEco project helps farmers and cooperatives collect rice straw instead of burning it, grow straw mushrooms on it and then compost it by machine. By 2024 it had trained 1,712 farmers and other stakeholders. A cooperative in the Mekong Delta reports that mushrooms and compost add USD 50 to 70 a hectare to farmers' income, compared with about USD 25 from selling loose straw.

Millets

Millets grow in dry areas, where the stalks feed animals through the dry months. Processing is a weak point and is not yet well developed.



By-products and Waste Generated at Different Nodes of the Millets Value Chain

Seed saving
Seed spoiled in damp storage

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Harvest and threshing
Stalks and chaff, fed to animals; grain lost when rain coincides with harvest and threshing

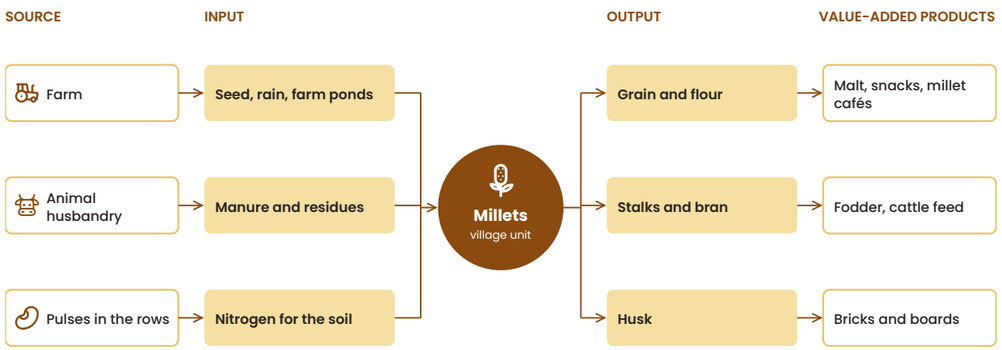
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Cleaning and destoning
Mud, dust and stones

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Hulling and flour
Husk, bran and broken grain as by-products with husk wasted at small units

Diagram of Inputs and Outputs



DRE Opportunities for Circularity in Millets

DRE OPPORTUNITY	CIRCULAR PRACTICE	DRE SOLUTIONS
A. Processing and Storage to Prevent Loss of Produce Risk Reduced Cost Effective	Keeping seed and grain dry and safe from pests, so that less is lost after harvest.	**Thresher with winnower, solar dryer, airtight or cooled seed store**
B. Decentralised Processing at Local Levels Income Gained Time Saved	Cleaning, destoning and hulling grain close to where it is grown, so that women do less hand pounding and economic gains stay in villages.	**Precleaner, dehuller, grader and destoner, flour mill, snack machines**
C. Turn Residues into a Second Product Income Gained	Selling husk from larger units to brick makers and other buyers who can use it in bulk.	**Husk collection and bagging, shared transport to buyers**
D. Return Nutrients to the Soil Soil Restored Inputs Saved Cost Effective	Growing pulses alongside millets, so that the soil gains nitrogen without bought fertiliser.	**Seed drill set for mixed rows, solar pump for farm ponds**
E. Use Residues as Feed Inputs Saved Income Gained	Chopping stalks and feeding bran and broken grain to animals near the processing unit.	**Chaff cutter, dehuller that separates bran**

~44%

of India's livestock feed comes from crop residues, so stalk quality matters

8 min

for a small machine to husk 5 kg of fonio, a job that takes hours by hand in West Africa

Value-Added Products from By-products and Waste



Photo: Medhi Jyoti, CC BY-SA 4.0

- **Millet flour**
  From hulled grain



Photo: Alex, CC BY-SA 3.0

- **Millet cookies**
  From broken grain



Photo: Judgefloro, CC BY-SA 4.0

- **Dry-season fodder**
  From stalks

Examples of Circularity in Millets



A solarised millet unit run by an SHG

Thirtha, Dharwad, Karnataka

Smt Bibi Jan is the convenor of the Bibi Fatima SHG and the CEO of Devadhanya FPO. Sahaja Samrudha helped her connect with SELCO Foundation for the solarisation of the SHG's millet processing unit, which processes 30 quintals of millet weekly into semolina, flour, health drinks and other products. The SHG also runs a community seed bank with over 120 endangered seed varieties.



Photo: United Nations in India

Odisha Millets Mission

Odisha

The state buys ragi from growers through millet mandis and has set up processing units at the gram panchayat level. Equipment is set up at processing centres and millet cafés are run by women's self-help groups and farmer producer organisations. Bringing cleaning and hulling close to growers has cut the hours women spend pounding grain by hand and processing food adds to their incomes.



Photo: AfroLegends

A small machine for husking fonio

Senegal and West Africa

Fonio is a small West African millet that women traditionally husk by hand, a few hours of work for just 2 kg. A machine built by Sanoussi Diakité, a Senegalese engineer, in 1993 husks 5 kg in about eight minutes. By 2010 he had made and sold over 100 machines, and by 2014 governments in countries such as Benin, Mali and Guinea had shown interest.

Mushroom

Mushroom growing is circular by design. Crop residues go in, food comes out, and the spent substrate can go back to the soil.



By-products and Waste Generated at Different Nodes of the Mushroom Value Chain

Substrate
Paddy straw and maize stalks that would otherwise be burnt

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Sterilising
Waste water; whole batches lost to contamination

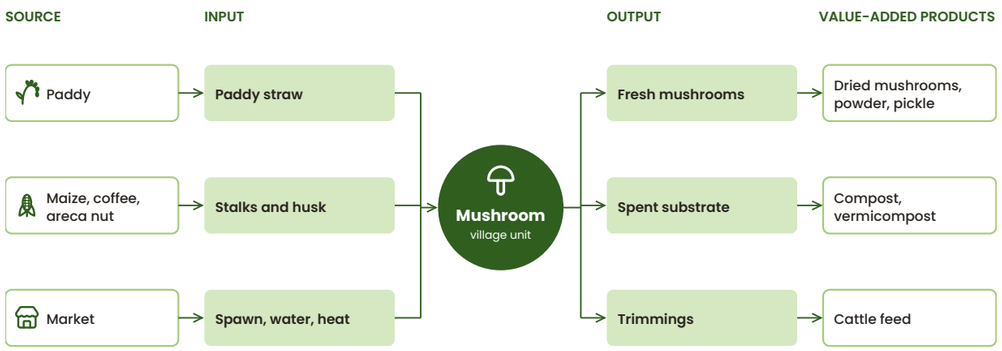
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Growing and harvest
30 to 70% of the crop lost above 35°C; mushrooms spoil in a day or two

←

After harvest
Spent substrate left in heaps

Diagram of Inputs and Outputs



DRE Opportunities for Circularity in Mushroom

DRE OPPORTUNITY	CIRCULAR PRACTICE	DRE SOLUTIONS
A. Processing and Storage to Prevent Loss of Produce Income Gained Risk Reduced	Using fans, foggers and shade to keep heat and humidity steady, so that fewer batches fail.	**Solar foggers, humidifiers and fans, controlled environment chamber**
B. Decentralised Processing at Local Levels Income Gained Risk Reduced	Drying or cooling mushrooms that cannot be sold the same day, and packing them for later sale.	**Solar dryer, solar cold room, packaging machine**
C. Turn Residues into a Second Product Income Gained Inputs Saved	Growing mushrooms on residues from other chains, such as areca husk, coffee husk and maize stalks.	**Chaff cutter or shredder, hot-water treatment tank**
D. Return Nutrients to the Soil Soil Restored Inputs Saved Cost Effective	Turning spent bags into compost or vermicompost and returning it to the fields.	**Shredder, vermicompost beds**
E. Use Residues as Feed Inputs Saved Cost Effective	Feeding clean spent straw from oyster mushroom bags to cattle as roughage.	**Chaff cutter, drying space**
F. Recover Energy Efficiently Inputs Saved Risk Reduced Time Saved	Sterilising substrate with safer heating, so that fewer batches are lost.	**Steam pasteuriser on biogas or an efficient stove**

30 to 70%

of the crop can be lost when the growing room goes above 35°C

5 to 6 kg

of spent substrate is left over for every kg of mushrooms grown

Value-Added Products from By-products and Waste



Photo: Goose Green Photography, CC BY 4.0

- **Dried mushrooms**
  From unsold fresh mushrooms



Photo: Yamaguchi Yoshiaki, CC BY-SA 2.0

- **Mushroom pickle**
  From stems and lower grades



Photo: peganum, CC BY-SA 2.0

- **Mushroom compost**
  From spent substrate

Examples of Circularity in Mushroom



Scaling up mushrooms with a chaff cutter

Kamrup Rural, Assam

Hemanta Nath began growing mushrooms after an introductory training from the Krishi Vigyan Kendra (KVK), arranged by Uttaran FPC, where he made two mushroom cylinders. With a 3 HP chaff cutter and a manual bag-filling machine, he has scaled up to 4,000 mushroom cylinders a season, three seasons a year, and from under 1 kg to 300 kg of mushrooms a month, sold to local grocery stores and wholesale buyers.



Photo: Fumikas Sagisavas, Wikimedia Commons (CC0)

Paddy straw mushrooms in Rajnagar

Kendrapara, Odisha

In Rajnagar block, over 200 families in women's self-help groups grow paddy straw mushrooms on local straw and earn about ₹7,000 a month. Traders pay about ₹180 a kg at the door, against ₹200 to ₹220 in retail shops. With no cold store in the district, growers must sell the same day, often at a lower price.



Photo: MarvinBikolano, Wikimedia Commons (CC BY-SA 4.0)

Mushrooms on crop waste in a drought area

Hurungwe, Zimbabwe

In Hurungwe District, women grow oyster mushrooms on maize stalks and other crop waste. When drought made these scarce, they switched to banana leaves and cotton waste. A lead farmer has trained 56 women from seven wards, and the group sells to local markets, schools and restaurants, with up to 40 kg from each growing cycle.

Pineapple

Pineapple's main loss is the whole fruit. The fruit floods the market at the peak of the season and cannot be kept cool for long.



By-products and Waste Generated at Different Nodes of the Pineapple Value Chain

Planting and crop care
Weeds; pests spread on untreated suckers

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Harvest and sale
Overripe fruit; up to 30% wasted in the glut season

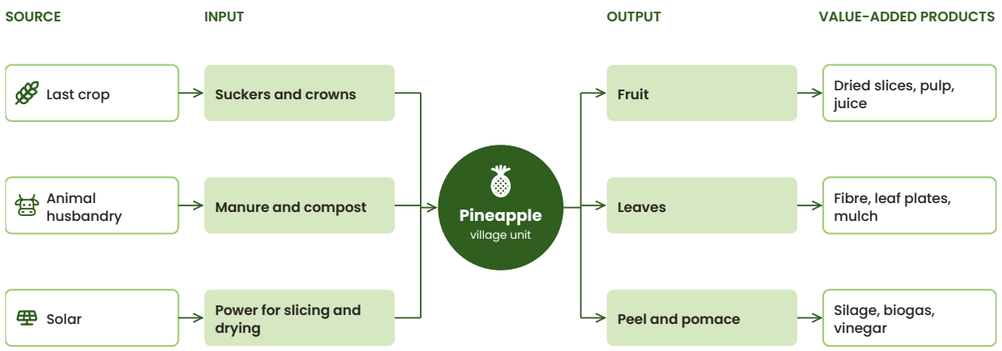
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Processing
Peel, core, crown and pomace, mostly with no buyer

←

Replanting
Old leaves, stems and crowns left to rot in the field

Diagram of Inputs and Outputs



DRE Opportunities for Circularity in Pineapple

DRE OPPORTUNITY	CIRCULAR PRACTICE	DRE SOLUTIONS
A. Processing and Storage to Prevent Loss of Produce Income Gained Risk Reduced	Using shaded collection points, crates and a cool store at the aggregation point, so that less fruit spoils on the way.	**Crates, solar cold room at the aggregation point**
B. Decentralised Processing at Local Levels Income Gained	Giving existing units reliable power, trained operators and buyers, so they can slice and pulp glut fruit.	**Solar power for slicer, pulper and packaging machine**
C. Turn Residues into a Second Product Income Gained	Extracting fibre from old leaves when the field is replanted, and composting what is left.	**Small motorised decorticator, washing and drying space**
D. Return Nutrients to the Soil Soil Restored Inputs Saved Cost Effective	Chopping old plants and spreading them on the field as mulch, instead of buying it.	**Shredder or chaff cutter, weeder**
E. Use Residues as Feed Inputs Saved Income Gained	Ensiling peel, core and pomace so that it keeps, and feeding it to cattle.	**Chopper, silage bags or pits**

Up to 30%
of pineapple is wasted in the glut season in the Northeast

13 million tonnes
of pineapple leaves are burnt or left to rot worldwide each year

Value-Added Products from By-products and Waste



Photo: EcoSilky

- **Pineapple leaf fibre cloth**
  From old leaves



Photo: JHistory, CC BY-SA 4.0

- **Dried pineapple rings**
  From glut fruit



Photo: PattayaPatrol, CC BY-SA 4.0

- **Cattle feed and silage**
  From peel and core

Examples of Circularity in Pineapple



Photo: P1898, Wikimedia Commons (CC BY 4.0)

Natural fibre unit at Tura

West Garo Hills, Meghalaya

The Central Agricultural University runs a unit at Tura where pineapple, banana and other leaves are passed through a decorticator to extract fibre, which is then spun and woven into mats and fabric. Farm women and rural youth are trained in extraction, spinning and weaving, so that leaves left after harvest can earn an income.



Photo: Challiyan, Wikimedia Commons (CC BY 3.0)

Leaf plates from a farmers' processor

Vazhakulam, Ernakulam, Kerala

Vazhakkulam Agro and Fruit Processing Company is a joint venture of the Kerala government and farmers in a district of about 5,000 pineapple growers. With ₹2.55 crore from the Rashtriya Krishi Vikas Yojana, it is adding a line to turn pineapple leaves into plates and cutlery, alongside its juice and pulp.



Photo: Ananas Anam

Leaf fibre for textiles

Philippines

Ananas Anam works with the Labo Progressive Multi-Purpose Cooperative to turn pineapple leaves left after harvest into fibre for a leather-like textile. Leaves are decorticated near the fields, and the leftover biomass goes back to the land as fertiliser. Farming families earn from a material that used to be burnt or left to rot.

Bamboo

Bamboo's losses are mostly damage to poles at harvest, rot for lack of treatment, and offcuts that are burnt as fuel.



By-products and Waste Generated at Different Nodes of the Bamboo Value Chain

Sourcing and harvest
Branches and tops; poles damaged by poor tools

→

Treatment and drying
Spent treatment solution; untreated bamboo that rots

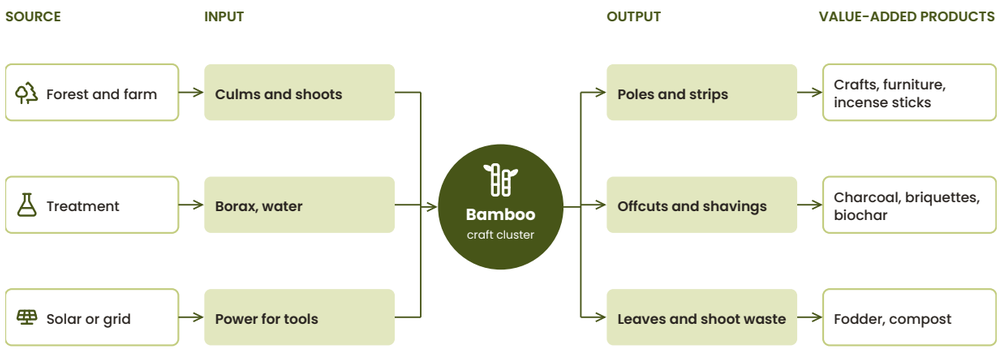
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Cutting and crafts
Offcuts, nodes, shavings and dust, burnt as household fuel

←

Shoot processing
Sheaths, peels and water; short shelf life

Diagram of Inputs and Outputs



DRE Opportunities for Circularity in Bamboo

DRE OPPORTUNITY	CIRCULAR PRACTICE	DRE SOLUTIONS
A. Processing and Storage to Prevent Loss of Produce Income Gained Risk Reduced	Using better cutting tools and treating culms, so that fewer poles are damaged or rot.	**Bamboo cutting machine, treatment tanks with a pump, solar dryer for culms**
B. Decentralised Processing at Local Levels Income Gained Time Saved	Splitting, slicing and polishing bamboo with small machines, so that less of each pole is wasted.	**Splitting, slicing, round stick, polisher, grinder, agarbatti unit**
C. Turn Residues into a Second Product Income Gained	Burning offcuts in an improved kiln that makes more charcoal and captures wood vinegar for sale.	**Shredder, improved kiln**
D. Return Nutrients to the Soil Soil Restored Income Gained	Turning offcuts into biochar in a shared kiln and returning it to farm soils.	**Improved kiln, crusher**
E. Use Residues as Feed Inputs Saved Cost Effective	Feeding bamboo leaves from harvested clumps to cattle and goats, especially in the dry season.	**Chaff cutter**
F. Recover Energy Efficiently Inputs Saved Income Gained	Making charcoal and briquettes from offcuts to replace wood fuel in homes and small units.	**Briquette press, improved kiln, efficient biomass dryer for culms and shoots**

80%

of bamboo artisans work only with hand tools

34.6 to 44.5%

charcoal yield from bamboo in an improved kiln, against 25 to 31% in pit and drum kilns

Value-Added Products from By-products and Waste



Photo: Ssemmanda Will, CC BY-SA 4.0

- **Bamboo charcoal**
  From offcuts



Photo: Oregon Department of Forestry, CC BY 2.0

- **Biochar**
  From offcuts and shavings



Photo: GIZ, CC BY-SA 4.0

- **Fuel briquettes**
  From shavings and dust

Examples of Circularity in Bamboo



Photo: Sagnik Samanta, Wikimedia Commons (CC BY-SA 4.0)

Uravu bamboo network

Wayanad, Kerala

Uravu, an artisan network formed in 1996, makes over 500 bamboo products along with bamboo houses and homestays. About 200 families are involved and about nine in ten workers are women; over 5,000 women have been trained. Some of the heavy cutting and splitting work is now done by machine.



Photo: Tim Brunauer, GIZ, Wikimedia Commons (CC BY-SA 4.0)

A community biochar unit

Umsli, Ri Bhoi, Meghalaya

In 2026, the Government of Meghalaya set up the first community biochar unit in the Northeast at Umsli. Locally harvested bamboo is turned into biochar for the region's acidic farm soils. The community also earns from the carbon the biochar stores, which gives a second income from the same bamboo.



Photo: Taekotukide, Wikimedia Commons (CC BY-SA 4.0)

A higher-yield bamboo charcoal kiln

Philippines

The Forest Products Research and Development Institute and DOST-PCAARRD developed a kiln that makes 34.6 to 44.5% charcoal from bamboo, against 25 to 31% in pit, drum and brick kilns. It also captures wood vinegar, which is sold as a second product from the same burn, and creates rural jobs.

Sugarcane`

Jaggery making is already partly circular, because bagasse fuels the furnace. The problem is how much of it the furnace wastes.



By-products and Waste Generated at Different Nodes of the Sugarcane and Jaggery Value Chain

Growing and harvest
Trash and tops; trash often burnt in the field

→

Crushing
Wet bagasse that still holds some juice

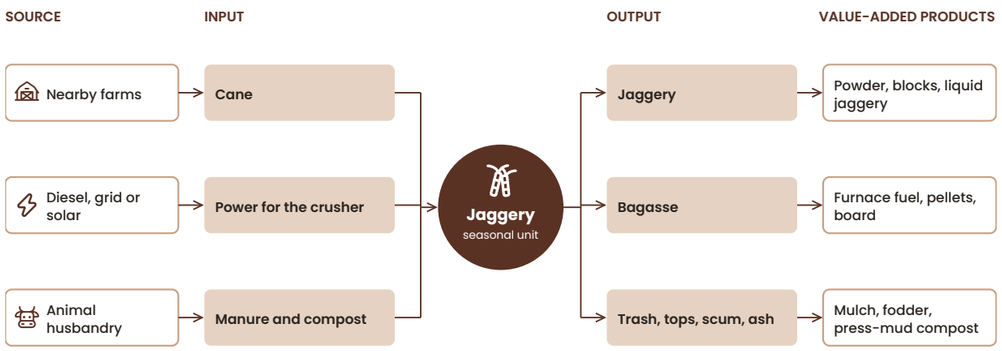
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Boiling
Heat lost up the chimney; wood and tyres burnt when bagasse runs short

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Scum, ash, washings
Meant for farmland, but rarely reach the fields

Diagram of Inputs and Outputs



DRE Opportunities for Circularity in Sugarcane and Jaggery

DRE OPPORTUNITY	CIRCULAR PRACTICE	DRE SOLUTIONS
A. Processing and Storage to Prevent Loss of Produce Income Gained Inputs Saved	Using efficient crushers so that less juice is left in the bagasse.	**Efficient crusher on a solar or grid motor, solar sugarcane juicer for juice sellers**
B. Decentralised Processing at Local Levels Income Gained	Making powder and packed jaggery near the farm, so that more of the value stays local.	**Pulveriser, packaging machine**
C. Turn Residues into a Second Product Income Gained	Pressing surplus bagasse into pellets once furnaces use less of it.	**Pellet press**
D. Return Nutrients to the Soil Soil Restored Inputs Saved Cost Effective	Leaving cane trash on the field as mulch, and returning furnace scum and ash to the soil.	**Trash shredder or mulcher, compost pit, soak pit for pan washings**
E. Use Residues as Feed Inputs Saved Cost Effective	Feeding green cane tops to cattle at harvest time, chopped so that less is wasted.	**Chaff cutter**
F. Recover Energy Efficiently Inputs Saved Risk Reduced	Burning bagasse in a furnace with a chimney and blower, or a gasifier, so that less fuel is needed.	**Improved furnace and chimney, electric blower on solar or grid power, gasifier**

Under 30%

efficiency in traditional bagasse furnaces

6.3 million tonnes

of surplus sugarcane trash a year in India, most of it burnt

Value-Added Products from By-products and Waste



Photo: Khalid Mahmood, CC BY-SA 3.0

- **Jaggery**
  From surplus cane



Photo: Anna Frodesiak, CC0

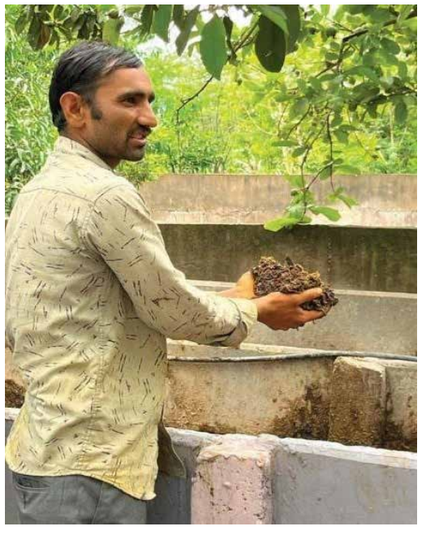
- **Bagasse fuel**
  From bagasse



Photo: Jonathan Wilkins, CC BY-SA 3.0

- **Trash mulch**
  From cane trash

Examples of Circularity in Sugarcane and Jaggery



Jaggery and dung on an integrated farm

Kalloli, Belagavi, Karnataka

Mr Ramesh Khangoudar practises integrated farming on 10 acres. He processes sugarcane into jaggery blocks and sells them under his brand, 'Krushi Sanjeevini Savayava Kendra', using machinery financed under the PM Formalisation of Micro Food Processing Enterprises (PMFME) scheme through the Karnataka Vikas Grameena Bank. He turns cattle dung into organic fertiliser through anaerobic digestion, makes fertiliser from cow urine, and sells his produce at a shop on his farm.



Photo: Jedesto, Wikimedia Commons (CC BY-SA 4.0)

A shared gasifier for five units

Gokak, Belagavi, Karnataka

TERI has set up a common facility centre where five small jaggery units share a biomass gasifier to heat their pans. The members sell their surplus bagasse to a partner, who supplies pellets or wood for the gasifier. The aim is to stop the burning of tyres and plastic, improve jaggery quality and make the work less smoky.



Photo: SanLuis2522, Wikimedia Commons (CC BY-SA 4.0)

Efficient panela furnaces

Colombia

Panela, Colombia's jaggery, employs about 350,000 people, nearly all in small family units. Improved furnaces developed with research centres reach 35 to 45% thermal efficiency, against 15 to 30% for traditional ones, using the same bagasse. Producers need less fuel and can stop burning wood and tyres.

Coconut

Coconut has an established circular industry in coir, yet most husk is still not used.



By-products and Waste Generated at Different Nodes of the Coconut Value Chain

Harvest and dehusking
Fronds and spathes; husk, of which only about 30% is used well

→

Copra drying
Shell; smoke and spoilage in fuel-fired drying

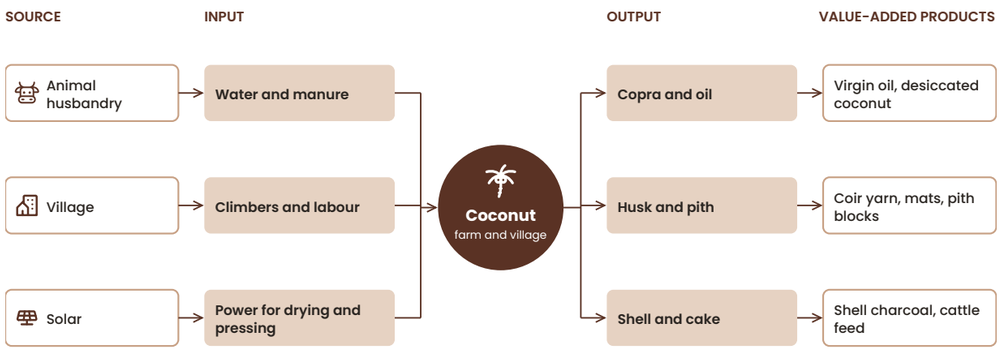
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Oil extraction
Oil cake, fed to cattle

←

Retting and spinning
Pith and retting water; retting takes 8 to 10 months

Diagram of Inputs and Outputs



DRE Opportunities for Circularity in Coconut

DRE OPPORTUNITY	CIRCULAR PRACTICE	DRE SOLUTIONS
A. Processing and Storage to Prevent Loss of Produce Income Gained Time Saved	Using bio-retting to turn husk into fibre in days, so that less husk is left to rot or burnt.	**Bio-retting tanks, motorised dehusker**
B. Decentralised Processing at Local Levels Income Gained	Turning husk into fibre in village units, and spinning it into yarn at home.	**Motorised dehusker, defibering machine, electronic ratt**
C. Turn Residues into a Second Product Income Gained	Making coir into erosion-control nets, and shells into charcoal.	**Twining and weaving frames, charcoal kiln**
D. Return Nutrients to the Soil Soil Restored Inputs Saved	Composting coir pith, and spreading husk and fronds around palms to hold moisture.	**Compost yard, turner or shredder**
E. Use Residues as Feed Income Gained Inputs Saved	Pressing oil in the village, so that the cake stays to feed local cattle.	**Solar oil mill, filter press**
F. Recover Energy Efficiently Inputs Saved Risk Reduced	Drying copra in solar dryers instead of over smoky fires, so less fuel is burnt and less copra spoils.	**Solar dryers, efficient shell-fired dryer**

~30%

of coconut husk in India is used well, according to the Union Minister of State (2025)

Over 7 lakh

rural workers in coir, about 80% of them women

Value-Added Products from By-products and Waste



Photo: Vis M, CC BY-SA 4.0

- **Coir doormats**
  From husk fibre



Photo: Vis M, CC BY-SA 4.0

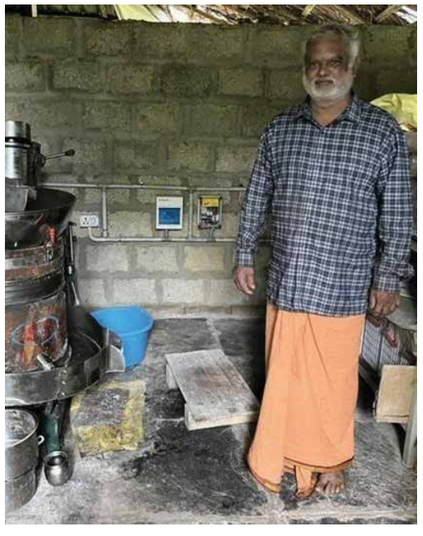
- **Coir rope**
  From husk fibre



Photo: Wikimedia Commons, CC BY 4.0

- **Shell crafts**
  From shell

Examples of Circularity in Coconut



Cold-pressed coconut oil in a remote village

Kodsinge, Sirsi, Uttara Kannada, Karnataka

Subray lives in a remote village. There were no flour mills, spice pounders or oil extraction units in the four surrounding villages, and people travelled 15 km to reach them. With a solar-powered oil extraction unit, flour mill and pulveriser, Subray and his family now press coconut and groundnut into organic cold-pressed oil, and offer pressing and milling as a service to the four villages.

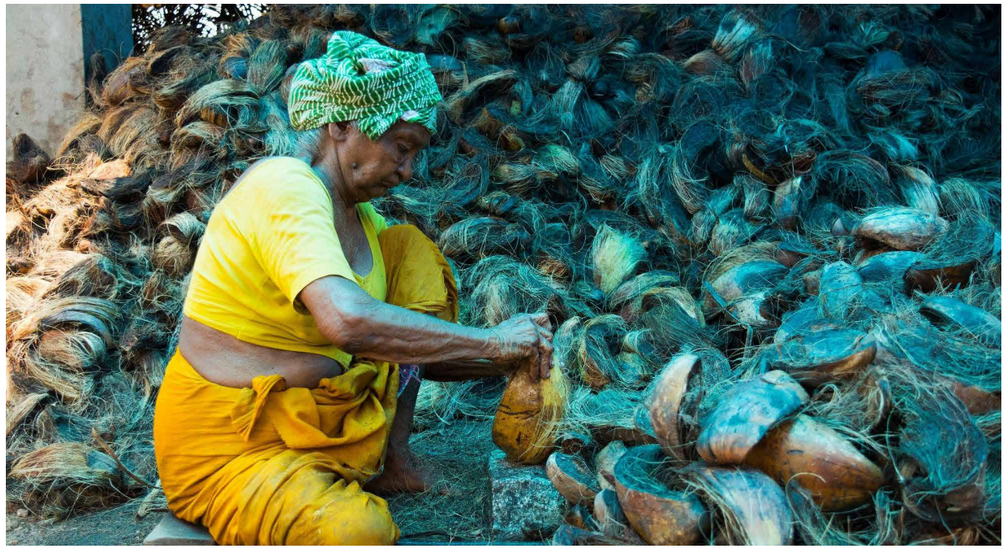


Photo: Shagil Kannur, Wikimedia Commons (CC BY-SA 4.0)

Village defibering units

Kannur, Kasaragod and Thrissur, Kerala

Kudumbashree women's groups run small units that turn raw husk into fibre and pith close to the farms. Each unit is run by five women from poor households and processes 2,500 to 3,000 husks a day. Coirfed, the state coir cooperative, buys the fibre, which gives the units an assured market.



Photo: Bricaniwi, Wikimedia Commons (CC BY-SA 4.0)

Mahila Coir Yojana

Coir-producing states

Under this Coir Board scheme, trained women spin coir fibre into yarn at home on motorised ratts. The Board pays 75% of the cost of the ratt. Motorised spinning replaces slow hand spinning and lets women earn without leaving home.

Areca Nut

Areca nut has one of the highest residue shares of any crop: husk is 60 to 80% of the fruit, and most of it is wasted.



By-products and Waste Generated at Different Nodes of the Areca Nut Value Chain

Plantation
Fallen leaves; 5 to 6 sheaths a palm a year

→

Harvest
Nuts lost when skilled climbers are scarce

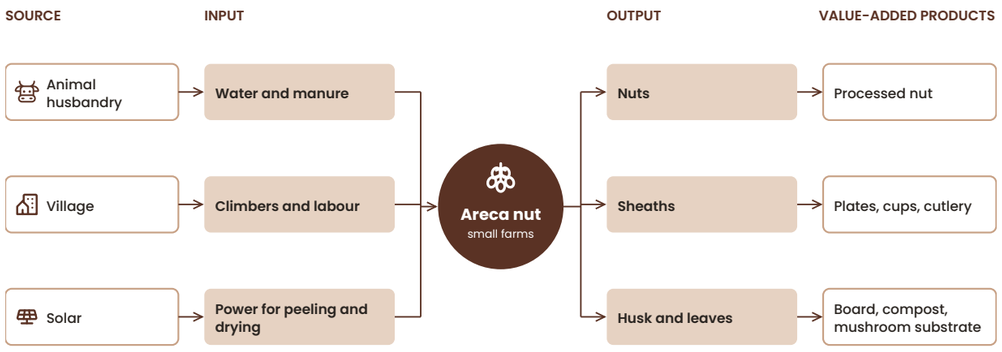
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Dehusking
Husk, mostly burnt as low-grade fuel or left in heaps

←

Boiling or drying
Husk and wood burnt, with smoke

Diagram of Inputs and Outputs



DRE Opportunities for Circularity in Areca Nut

DRE OPPORTUNITY	CIRCULAR PRACTICE	DRE SOLUTIONS
A. Processing and Storage to Prevent Loss of Produce Income Gained Time Saved Risk Reduced	Using a mechanical climber to harvest on time when skilled climbers are scarce. Drying nuts in solar dryers so that less husk and wood are burnt.	**Tree climber, solar dryer, efficient furnace**
B. Decentralised Processing at Local Levels Time Saved Income Gained	Peeling dried nuts with a small machine, which also leaves the husk in one place for reuse.	**Motorised peeler, solar or grid power**
C. Turn Residues into a Second Product Income Gained Cost Effective	Collecting fallen sheaths and pressing them into plates and cups for sale.	**Hydraulic plate press, washing tank**
D. Return Nutrients to the Soil Soil Restored Inputs Saved Cost Effective	Shredding husk and composting it with fallen leaves, or spreading it around the palms.	**Husk shredder, composting space**
E. Use Residues as Feed Inputs Saved Cost Effective	Grinding sheaths that are not used for plates and mixing them into cattle feed.	**Disintegrator, grinder and mixer, chaff cutter**

60 to 80%

of the fresh fruit is husk

~25%

higher incomes for members of women's plate-making groups in Mizoram

Value-Added Products from By-products and Waste



Photo: Rumi Borah, CC BY-SA 4.0

- **Areca leaf plates**
  From leaf sheaths



Photo: Manojk, CC BY-SA 4.0

- **Husk vermicompost**
  From husk



Photo: MarvinBikolano, CC BY-SA 4.0

- **Mushroom substrate**
  From shredded husk

Examples of Circularity in Areca Nut



Photo: Shaphrangstar Marbaniang, Wikimedia Commons (CC BY-SA 4.0)

Vermicompost from areca husk

K. Ganadakatte, Channagiri, Davanagere, Karnataka

Areca nut husk is bulky and fibrous, and decomposes very slowly, often taking up to two years. SELCO Foundation supported R. Lohith with an areca husk shredder, a solar drying approach and guidance on vermicomposting using husk powder. Drying takes about 3 days in the solar dryer instead of about 2 months in the sun, and the powdered husk now decomposes in a few weeks. He is also testing it as mushroom substrate and areca peat.



Photo: Kakkara, Wikimedia Commons (CC BY-SA 3.0)

Sheath plate makers

Kolasib and Mamit, Mizoram

A 43-member women farmers' club and a 182-member village organisation, supported by ICAR, press fallen sheaths into plates on 1 HP machines. They make between 190,000 and 349,000 plates a year, and members earn about 25% more than non-members.



Photo: Slashme, Wikimedia Commons (CC BY-SA 4.0)

Air fresheners from husk

Shivamogga, Karnataka

Mystic Aromatics, a rural start-up, presses areca husk into a board and makes biodegradable air fresheners from it. This creates a market product from husk that is usually thrown away or burnt.

Coffee

Most of a coffee cherry is not the bean. The pulp, husk and waste water are usually thrown away, and the acidic water can pollute streams.



By-products and Waste Generated at Different Nodes of the Coffee Value Chain

Plantation
Leaf litter and prunings, left under the trees

→

Wet processing
Pulp, mucilage and waste water

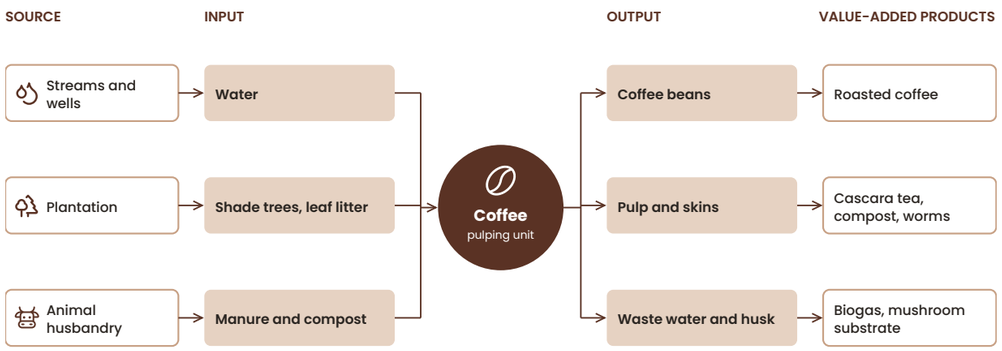
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Dry processing
Quality lost when rain coincides with drying

←

Curing
Husk

Diagram of Inputs and Outputs



DRE Opportunities for Circularity in Coffee

DRE OPPORTUNITY	CIRCULAR PRACTICE	DRE SOLUTIONS
A. Processing and Storage to Prevent Loss of Produce Income Gained Risk Reduced	Drying coffee in solar dryers, so that rain does not spoil the beans.	**Solar bubble dryer**
B. Decentralised Processing at Local Levels Soil Restored Inputs Saved	Pulping at a shared unit that reuses its water, so that small growers can wet-process with less waste.	**Eco-pulper, tank and recirculation pump on solar or grid power**
C. Turn Residues into a Second Product Income Gained	Drying cherry skins cleanly and selling them as a tea called cascara.	**Solar dryer, food-grade storage**
D. Return Nutrients to the Soil Soil Restored Inputs Saved Cost Effective	Composting pulp, or feeding it to worms, and returning it to the coffee plants.	**Compost turner or shredder, vermicompost beds**
E. Use Residues as Feed Inputs Saved	Feeding small amounts of pulp to cattle, or feeding worms raised on pulp to poultry and fish.	**Vermicompost beds, drying space**
F. Recover Energy Efficiently Soil Restored Inputs Saved	Treating waste water in a digester that makes gas, and using the cleaner water for irrigation.	**Digester, pump**

Up to 70,000 litres
of effluent per tonne of fresh cherry from traditional wet processing

Under 2,000 litres
per tonne when eco-pulpers remove the mucilage mechanically

Value-Added Products from By-products and Waste



Photo: Raimond Spekking, CC BY-SA 4.0

- **Cascara tea**
  From cherry skins



Photo: Erinamukuta, CC BY-SA 4.0

- **Pulp compost**
  From pulp



Photo: Gachwala

- **Oyster mushrooms**
  From pulp and husk

Examples of Circularity in Coffee



Photo: Yercaud-elango, Wikimedia Commons (CC BY-SA 4.0)

A low-water pulping unit

Somwarpet, Kodagu, Karnataka

A ₹40 lakh pulping unit run by the Mutt plantation stores and reuses its water, so it releases far less waste water to streams. It serves coffee growers of the area, who do not have to pulp on their own farms. The Coffee Board has also offered finance for modern pulping units in selected villages.



Photo: Ludger001, Wikimedia Commons (CC BY-SA 4.0)

Coffee pulp composted by cooperatives

Seven counties, Kenya

The ARABIKA project, led by CEFA with AVSI and the E4Impact Foundation, works with 21 cooperatives and about 30,000 farmers. Cooperatives mix coffee pulp, about 40% of the fresh fruit, with green plant matter to make compost for their farms. The project also plans to give seven cooperatives eco-pulpers that use less water and energy.



Photo: SuSanA Secretariat, Wikimedia Commons (CC BY 2.0)

Worms, fish and poultry on coffee waste

Ethiopia, Kenya and Tanzania

Debre Berhan University, with ILRI and partners, feeds coffee pulp from processors to earthworms. The compost goes to vegetable gardens, and the surplus worms are fed to chickens and fish. A waste that pollutes streams becomes a cheaper fertiliser and feed.

Banana

Banana leaves more biomass behind than most value chains. Once the banana bunch is cut, about 60 tonnes a hectare of stem and leaves are usually burnt or dumped.



By-products and Waste Generated at Different Nodes of the Banana Value Chain

Growing
Dry leaves, used for mulch or plates

→

Harvest
Stem, leaves, roots and flower, mostly burnt or dumped

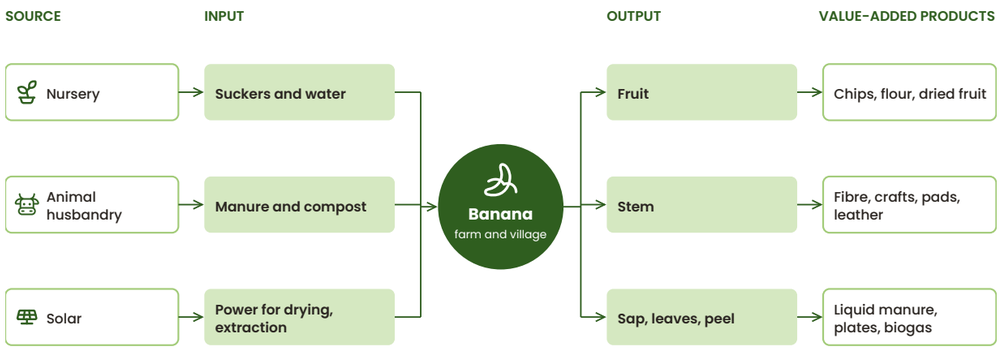
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Ripening and sale
Overripe fruit; about 7.6% lost on the way to market

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Processing and fibre
Peel, sap, core and pulp; the pseudostem alone is about a third of the plant's biomass

Diagram of Inputs and Outputs



DRE Opportunities for Circularity in Banana

DRE OPPORTUNITY	CIRCULAR PRACTICE	DRE SOLUTIONS
A. Processing and Storage to Prevent Loss of Produce Income Gained Risk Reduced	Storing and ripening fruit in cool rooms, so that less is lost between farm and market.	**Ripening chamber or solar cold room**
B. Decentralised Processing at Local Levels Income Gained	Slicing, drying and grinding raw bananas into powder and chips near the farm.	**Banana mill, chips maker, packaging machine**
C. Turn Residues into a Second Product Income Gained	Extracting fibre from the stem and making it into crafts and textiles, and composting the pulp.	**Stem cutter, extractor, shredder, spinning, warping, weaving**
D. Return Nutrients to the Soil Soil Restored Inputs Saved Income Gained	Pressing sap from the stem, enriching it and spraying it on crops.	**Sap press, storage tanks**
E. Use Residues as Feed Inputs Saved Cost Effective	Chopping stem, leaves and peel and feeding them to cattle.	**Chaff cutter, shredder**
F. Recover Energy Efficiently Inputs Saved	Digesting chopped stem and peel to make gas for the processing unit.	**Shredder, biodigester**

~60 tonnes

a hectare of stem, leaves and roots left after harvest

30 million tonnes

of banana pseudostem is thrown away in India each year, which could yield about 1.5 million tonnes of fibre.

Value-Added Products from By-products and Waste



Photo: Denis Kasozi, CC BY 4.0

- **Banana fibre bags**
  From pseudostem



Photo: Ramesh Kunnappully, CC BY-SA 4.0

- **Banana chips**
  From unsold raw fruit



Photo: Codegeass123, CC BY-SA 4.0

- **Leaf plates**
  From leaves

Examples of Circularity in Banana



Photo: Down To Earth

Banana fibre crafts

Shravasti, Uttar Pradesh

The Baudhanchal self-help group has 20 core members and about 30 other women. Using a fibre extractor, they turn banana stems into fibre and make jewellery, dolls and trays. Each artisan earns about ₹10,000 a month, and 80% of the group's income goes to the artisans.



Photo: Abhijeet, Wikimedia Commons (CC BY-SA 3.0)

A district banana economy

Burhanpur, Madhya Pradesh

Burhanpur has chosen banana as its product under the One District One Product programme. Self-help groups make stems into fibre, crafts, sanitary pads and plant-based leather, sap into fertiliser, and fruit into chips and powder, sold under one brand. One unit employs over 50 women, and over 200 enterprises have received PMFME loans.



Photo: Fridah Kaguri, Wikimedia Commons (CC BY-SA 4.0)

Banana fibre for rugs and hair extensions

Near Kampala, Uganda

TEXFAD works with seven farmer groups and buys dried banana fibre from them at about USD 2.7 a kg. It makes rugs, lampshades and hair extensions from the fibre. Farmers earn from stems that they used to leave to rot after harvest.

Jackfruit

Jackfruit is lost mostly as whole fruit that ripens, falls and rots under the trees, because markets and buyers are limited.



By-products and Waste Generated at Different Nodes of the Jackfruit Value Chain

Trees and harvest
Fruit that falls and rots; over half wasted nationally

→

Cutting and cleaning
Rind, core and seeds; sticky latex slows the work

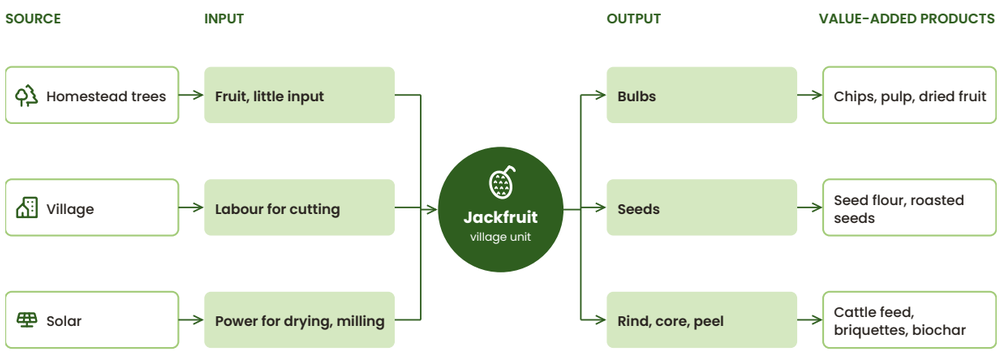
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Processing
Rind and core; little processing capacity near the trees

←

Seeds, rind and core
Seeds cooked at home only; rind and core left to rot

Diagram of Inputs and Outputs



DRE Opportunities for Circularity in Jackfruit

DRE OPPORTUNITY	CIRCULAR PRACTICE	DRE SOLUTIONS
A. Processing and Storage to Prevent Loss of Produce Income Gained Risk Reduced	Harvesting with poles and nets and collecting fruit at a village point before it falls and rots.	**Harvesting poles and nets, collection point**
B. Decentralised Processing at Local Levels Income Gained Time Saved	Peeling, cutting and drying bulbs close to the trees, so that more fruit is used.	**Peeler and cutter, solar dryer, pulp maker, chips maker, packaging machine**
C. Turn Residues into a Second Product Income Gained	Drying seeds and milling them into flour for baking and cooking.	**Solar dryer, flour mill**
D. Return Nutrients to the Soil Soil Restored Cost Effective	Turning dried peel into biochar and returning it to gardens and fields.	**Solar dryer, small kiln, crusher**
E. Use Residues as Feed Inputs Saved Cost Effective	Chopping or ensiling rind and core and feeding it to cattle.	**Chopper, silage bags**
F. Recover Energy Efficiently Inputs Saved	Drying peel for fuel or briquettes, or digesting it for gas.	**Solar dryer, briquette press, small digester**

Over 50%

of India's jackfruit is wasted; over 80% in parts of the Northeast

25 to 35%

of a jackfruit is eaten. The rest is peel, core and seeds.

Value-Added Products from By-products and Waste



Photo: Vaikoovery, CC BY 3.0

- **Jackfruit chips**
  From unsold fruit



Photo: Gharouni, CC BY-SA 4.0

- **Seed flour**
  From seeds



Photo: Njata123, CC BY-SA 4.0

- **Cattle feed**
  From rind and core

Examples of Circularity in Jackfruit



Photo: Scott Dexter, Wikimedia Commons (CC BY-SA 2.0)

Machine-peeled fruit for local markets

Gajapati, Odisha

Tribal women in Gajapati district use a machine adapted from a wood planer that peels a jackfruit in about two minutes, a job that takes much longer by hand. They sell the cut fruit locally at a higher price than whole fruit. One woman reports that her earnings rose sixfold.



Photo: Suyash Dwivedi, Wikimedia Commons (CC BY-SA 4.0)

Mission Jackfruit

Meghalaya

The Government of Meghalaya's draft mission plans 200 household and village units, each costing about ₹2 lakh, with dryers, peelers and fryers. Self-help groups and producer organisations would collect the fruit. The plan is built around small units close to the trees, in a region that loses about ₹434 crore of fruit each season.



Photo: Billjones94, Wikimedia Commons (CC BY-SA 4.0)

Women turning jackfruit waste into fuel

Akwa Ibom, Nigeria

Women in Essien Udim, supported by the Women in Nature Conservation Organization, make jackfruit into porridge, chips and smoothies. They dry the seeds in the sun so they keep through the off-season, and dry the peel for cooking fuel. Over two years they processed 100 kg of dried peel and began making briquettes and biochar.

Eri Silk

Eri is circular by tradition. The worms eat castor leaves, the cocoons are spun into silk, and the pupae are eaten or sold.



By-products and Waste Generated at Different Nodes of the Eri Silk Value Chain

Host plants
Rearing limited by the supply of castor leaves

→

Rearing
Droppings and leftover leaves, left in heaps

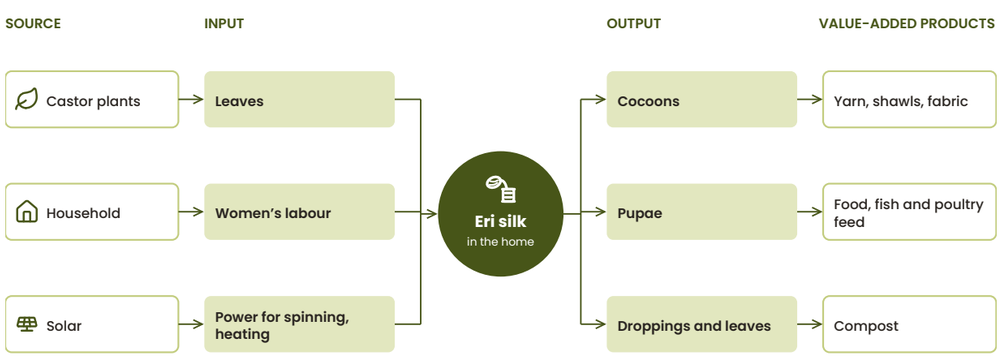
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Cocoon processing
Pupae; degumming water poured away

←

Spinning and weaving
Thread waste; hand spinning gives only 15 to 30 g a day

Diagram of Inputs and Outputs



DRE Opportunities for Circularity in Eri Silk

DRE OPPORTUNITY	CIRCULAR PRACTICE	DRE SOLUTIONS
A. Processing and Storage to Prevent Loss of Produce Income Gained Risk Reduced	Growing castor close to homes so that leaves are always at hand, and fewer rearing cycles are lost.	**Solar pump for castor plots, oil expeller for castor seed**
B. Decentralised Processing at Local Levels Income Gained Time Saved	Spinning on small machines at home, so that women make more yarn in less time.	**Spinning machine, re-reeling, yarn winding, efficient loom**
C. Turn Residues into a Second Product Income Gained	Keeping pupae as food for the household or selling them locally, cooled or dried so that they last.	**Solar dryer, small cooler**
D. Return Nutrients to the Soil Soil Restored Cost Effective	Composting droppings and leftover leaves and returning them to castor and food plots.	**Compost pit or vermibeds**
E. Use Residues as Feed Income Gained Inputs Saved	Drying and milling surplus pupae into feed for fish and poultry.	**Solar dryer, pulveriser**

15 to 30 g

of yarn a day with a hand spindle (takli), against up to 200 g on a spinning machine

~88%

of a fresh eri cocoon's weight is the pupa; the silk shell is only about 12%. The pupae contain about 52% protein.

Value-Added Products from By-products and Waste



Photo: Simtastic01, CC BY-SA 4.0

- **Eri silk yarn and cloth**
  From pierced cocoons



Photo: Fumikas Sagisavas, CC0

- **Pupae as food**
  From pupae



Photo: Øyvind Holmstad, CC BY-SA 4.0

- **Poultry feed**
  From surplus pupae

Examples of Circularity in Eri Silk



Photo: Sailesh Patnaik, Wikimedia Commons (CC BY-SA 4.0)

Household eri rearing

Assam

Women in Assam, many from Adivasi communities, rear eri worms on castor leaves, spin the cocoons on a hand spindle called a takli, and eat or sell the pupae. Nothing in the cocoon is wasted, and the pupae often earn more than the silk. Rearing and spinning fit around other household and farm work.



Photo: Khubaib Sani, Wikimedia Commons (CC BY-SA 4.0)

Solar machines for silk spinners

Assam, Meghalaya, Mizoram

SELCO Foundation has installed over 300 solar and electric eri spinning machines across Assam, Meghalaya and Mizoram. A machine spins up to 200 g of yarn a day, against 15 to 30 g on a hand spindle (takli). In Warmawsaw, Philim Makri learnt to service her own machine and has since trained over 50 women to use one. Another spinner, Jacinta, used the time she saved to start sewing clothes.



Photo: Tosheka Textiles

Eri silk and pupae feed on castor farms

Makueni, Kenya

In semi-arid Makueni, Tosheka Textiles supplies farmers with free castor seed. The leaves feed eri silkworms, and the seed is sold as an oil crop. About 50 local women rear the worms and spin the fibre, and the wider castor project reaches around 1,000 farmers. Surplus pupae are dried in a solar dryer and ground into protein-rich animal feed.

Oilseeds

Oilseeds give two main products, oil and cake. The cake can feed animals or go back to the soil.



By-products and Waste Generated at Different Nodes of the Oilseeds Value Chain

Growing and harvest

Haulms, fed as fodder; stalks, burnt as fuel

→

Shelling and storage

Shells and husk; mould and pests in damp storage

↓

Pressing

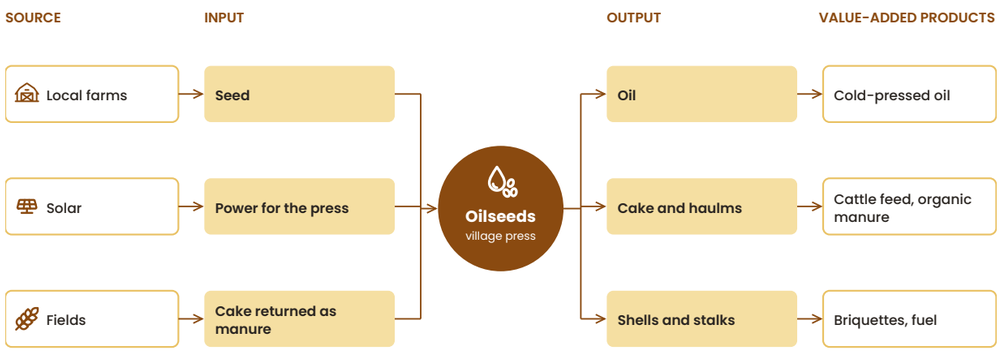
Oil cake

←

Shells and stalks

Burnt in the open or sold to briquette makers

Diagram of Inputs and Outputs



DRE Opportunities for Circularity in Oilseeds

DRE OPPORTUNITY	CIRCULAR PRACTICE	DRE SOLUTIONS
A. Processing and Storage to Prevent Loss of Produce Income Gained Risk Reduced	Drying seed well and storing it in airtight bags, so that mould and pests do less damage.	**Thresher with winnower, solar dryer, hermetic bags**
B. Decentralised Processing at Local Levels Income Gained	Using improved stoves or briquettes to roast seed and heat processing. Pressing oil in the village, so that the oil is sold and the cake feeds local animals.	**Improved roasting stove, briquette press. Solar oil mill, filter press, packaging machine**
C. Turn Residues into a Second Product Income Gained	Pressing shells and husk into briquettes for local heat or for sale.	**Groundnut decorticator, briquette press**
D. Return Nutrients to the Soil Soil Restored Inputs Saved Cost Effective	Grinding cake from neem, castor and other non-edible seeds and spreading it on fields.	**Grinder, oil expeller**
E. Use Residues as Feed Inputs Saved Income Gained	Feeding edible cake and chopped groundnut haulms to cattle.	**Chaff cutter, solar oil mill**

4.3 million tonnes

of oil cake and meal exported from India in 2024–25, mostly to Bangladesh, South Korea and Thailand

7%

nitrogen in groundnut cake, with 1.5% each of phosphate and potash, which makes it a rich manure

Value-Added Products from By-products and Waste



Oil cake cattle feed
From edible oil cake



Photo: Ranjithkumar Murugesan, CC0

Oil cake manure
From non-edible oil cake



Photo: Thamizhpparithi Maari, CC BY-SA 3.0

Shell fuel
From groundnut shells

Examples of Circularity in Oilseeds



Solar oil pressing, with cake sold as feed

Chikkahesarur, Raichur, Karnataka

Gurusiddeshwar Meti saw the need for an organic oil extraction unit in his village, as villagers travelled 55 km to reach one. He set up a solar-powered oil extraction unit and now presses oil for farmers in Raichur and Koppal districts. The oil cake is sold to dairy farmers as cattle feed for ₹20 a kg.



Photo: GIZ, Wikimedia Commons (CC BY-SA 4.0)

Residues bought for briquettes

18 states

Punjab Renewable Energy Systems buys groundnut shells, soya husk, straw and cane trash from about 200,000 farmers and makes them into briquettes and pellets for industry. Farmers earn cash for residues that were burnt, though the material, and its nutrients, leave the farm.



Photo: Maltiti Aminatu, Wikimedia Commons (CC BY-SA 4.0)

Groundnut mills for women

Gwollu and Buoti, Upper West Region, Ghana

In 2024, the Community Development Alliance set up groundnut processing mills at Gwollu and Buoti for women's groups, as part of a programme that supports 650 women groundnut farmers and processors. The women no longer have to carry groundnuts to distant villages to extract oil, which saved them cost and travel.

Maize

Maize leaves stalks, husks and cobs. Stalks are often used as feed and cobs for fuel.



By-products and Waste Generated at Different Nodes of the Maize Value Chain

Growing and harvest
Thinnings and stalks; stalks burnt in some areas

→

Dehusking and shelling
Husks and bare cobs

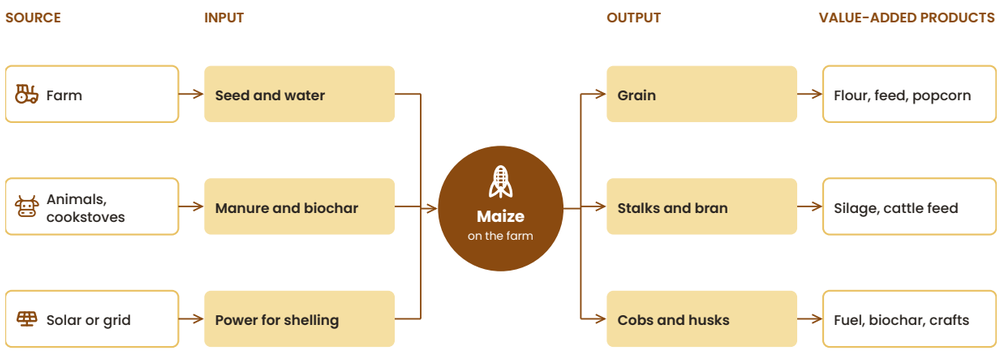
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Drying and storage
Pests and mould in storage; about 6% of maize is lost on farms in all

←

Cobs and stalks
Burnt as cooking fuel in open fires, with smoke

Diagram of Inputs and Outputs



DRE Opportunities for Circularity in Maize

DRE OPPORTUNITY	CIRCULAR PRACTICE	DRE SOLUTIONS
A. Processing and Storage to Prevent Loss of Produce Income Gained Risk Reduced Cost Effective	Drying grain well and storing it in airtight bags, so that pests do less damage.	**Solar dryer, hermetic bags, moisture meter**
B. Decentralised Processing at Local Levels Time Saved Income Gained	Shelling with a power sheller and milling in the village, so that women do less hand work.	**Power sheller, flour mill, corn grill fan and popcorn maker for vendors**
C. Turn Residues into a Second Product Income Gained	Chopping stalks and husks for use as mushroom substrate, then composting the spent substrate.	**Chaff cutter, hot-water treatment tank**
D. Return Nutrients to the Soil Soil Restored Inputs Saved	Making biochar from stalks and cobs in a portable kiln and returning it to the fields.	**Portable kiln, crusher**
E. Use Residues as Feed Inputs Saved Cost Effective	Chopping stalks or making silage and feeding it to cattle.	**Chaff cutter, silage bags**
F. Recover Energy Efficiently Inputs Saved Soil Restored	Burning cobs in stoves that cook food and leave biochar behind.	**Improved cookstove or small kiln**

~40%

weight loss to pests in ordinary bags over 24 weeks, against under 3% in airtight bags

Up to 25%

higher crop yields after two years of using biochar from cookstoves in Odisha

Value-Added Products from By-products and Waste



Photo: Tractorboy60, public domain

- **Maize silage**
  From green stalks



Photo: Thelmadatter, CC BY-SA 3.0

- **Husk crafts**
  From husks



Photo: Juliancolton, public domain

- **Cob briquettes**
  From cobs

Examples of Circularity in Maize



Photo: USFWS Mountain-Prairie, Wikimedia Commons (public domain)

Fish feed from maize and rice bran

Kalpani Farmer Producer Company

Mr Abul Kalam makes fish feed from local raw materials such as maize, rice bran and mustard cake, and runs a rice processing unit with an interchangeable motor for shelling and grinding maize. He is now adding a feed mixer and a solar dryer, because with hand mixing and no proper drying, fungus grows on the feed within one to two days. He earns a gross margin of ₹8 a kg.

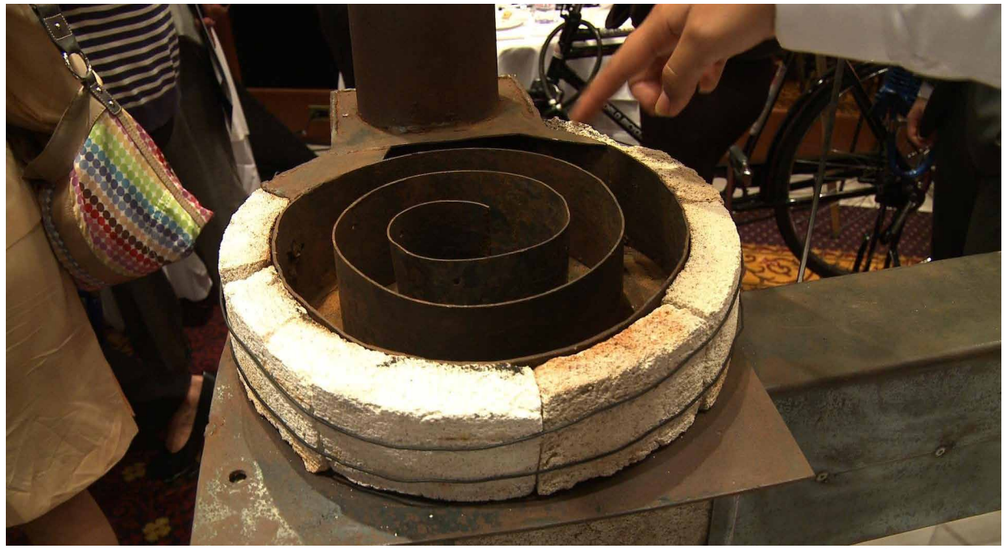


Photo: USAID, Wikimedia Commons (public domain)

Biochar cookstoves

Balangir and Nuapada, Odisha

CIFOR-ICRAF and GIZ worked with women to introduce cookstoves that burn crop residues such as maize cobs and leave biochar behind. The women use the biochar in gardens and fields. The stoves cut smoke and carbon dioxide by up to 25%, and crop yields rose by up to 25% after two years.



Photo: Kalgudi

Airtight storage bags

Across Africa

PICS bags, developed by Purdue University and partners, are triple-layer bags that seal out air so insects die without chemicals. In a Kenyan trial, maize in ordinary bags lost about 40% of its weight to pests in 24 weeks, against under 3% in PICS bags. Farmers can keep grain for food or sell later at a better price.

Vegetables

Vegetables lose most at the fresh produce stage itself. Tomatoes spoil on the way to market, and onions lose 30 to 40% in ordinary storage.



By-products and Waste Generated at Different Nodes of the Vegetables Value Chain

Growing and harvest
Vines, stalks and culls; 8.4% of tomato lost on the farm

→

Curing and storage
Rotten and sprouted onion and garlic bulbs

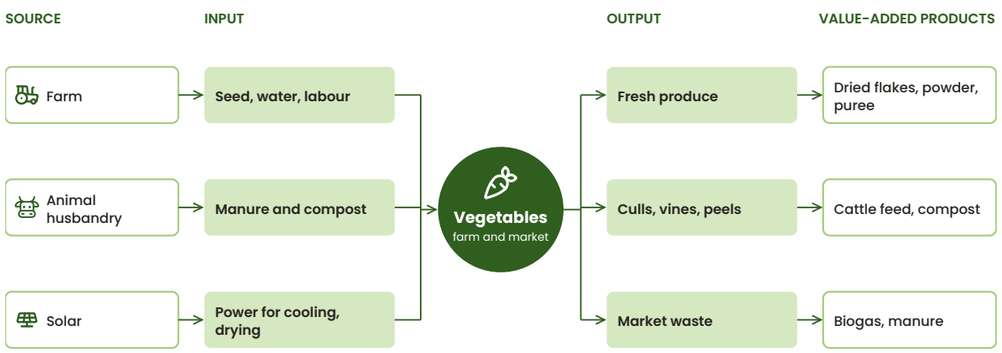
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Transport and market
Unsold produce, mostly sent to landfill

←

Processing
Peels and seeds

Diagram of Inputs and Outputs



DRE Opportunities for Circularity in Vegetables

DRE OPPORTUNITY	CIRCULAR PRACTICE	DRE SOLUTIONS
A. Processing and Storage to Prevent Loss of Produce Income Gained Risk Reduced	Storing cured bulbs in ventilated or low-energy stores, so that fewer rot or sprout.	**Ventilated storage, low-energy store with solar fans**
B. Decentralised Processing at Local Levels Income Gained Risk Reduced	Cooling fresh produce in shared cold rooms, and drying glut produce into flakes and powder.	**Solar cold storage, washer and peeler, tomato blancher, slicer, dryers**
C. Turn Residues into a Second Product Income Gained	Turning tomato and onion peels and seeds from processing into powder or seed oil.	**Solar dryer, pulveriser**
D. Return Nutrients to the Soil Soil Restored Inputs Saved Cost Effective	Composting vines, stalks and rotten produce and returning them to the next crop.	**Shredder, compost pit**
E. Use Residues as Feed Inputs Saved Cost Effective	Feeding culled produce to cattle on the farm.	**Graders**
F. Recover Energy Efficiently Inputs Saved	Digesting market waste to make power for the market's own cold rooms.	**Shredder, digester, biogas generator**

11.62%

of tomato and 7.27% of onion lost between farm and market

10 tonnes

of market waste a day turned into biogas at Bowenpally market, Hyderabad

Value-Added Products from By-products and Waste



Photo: Fumikas Sagisavas, CC0

- **Dried vegetable flakes**
  From glut produce



Photo: CDD India, CC BY-SA 4.0

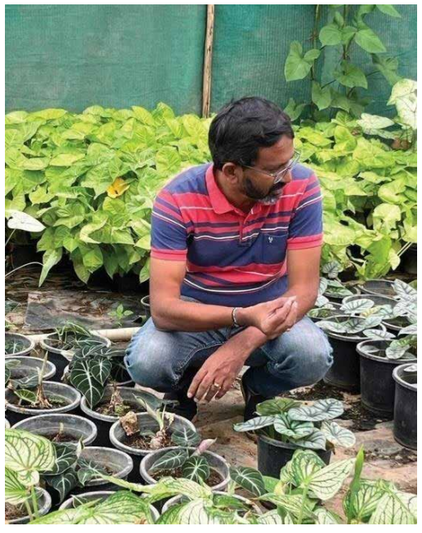
- **Compost**
  From vines and rotten produce



Photo: MGB CEE, CC BY-SA 4.0

- **Biogas**
  From market waste

Examples of Circularity in Vegetables



Cold storage and hydroponic fodder

Dharwad, Karnataka

Dr Narsana Gouda Veerapur grows exotic vegetables, orchids and mushrooms, and follows practices such as rainwater harvesting and vermicomposting. With SELCO Foundation, he set up a 5-tonne cold store and a solar-powered hydroponic fodder unit. The cold store holds the organic produce of 25 local farmers, sold at a weekly 'savayava sante' (organic market) on his farm, and the hydroponic fodder has improved the fat and protein content of the milk.



Photo: Christian Science Monitor

A vegetable market that runs on its own waste

Bowenpally, Hyderabad, Telangana

The agricultural market committee at Bowenpally shreds about 10 tonnes of vegetable waste a day and digests it to make biogas. The gas runs a generator that powers the market's cold rooms, pumps, streetlights and stalls, and the slurry is used as manure.



Photo: ColdHubs

Pay-as-you-store cold rooms

Nigeria

ColdHubs runs solar walk-in cold rooms in markets and farm clusters, where farmers and traders pay a small fee for each crate stored per day. It has set up 58 hubs and created over 80 jobs for women, who run the stations.

Index of DRE Opportunities

All 91 opportunities, grouped by type. Page numbers point to each value chain's opportunities page.

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Circularity in DRE Livelihood Value Chains

Understanding the role of circularity in agricultural value chains and the role of DRE productive use solutions

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