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Joint UNIDO-UNEP Program on Resource Efficiency and Cleaner Production (RECP) in Developing and Transition Countries

Industrial Waste Minimization for Low Carbon Production

Rice Sector Assessment

Version1.0, August 2014

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Foreword

The *Industrial Waste Minimization for Low Carbon Production* project falls under the umbrella of the global joint UNIDO-UNEP Programme on Resource Efficiency and Cleaner Production (RECP) in Developing and Transition Countries, and is financed by the Swiss State Secretariat for Economic Affairs (SECO, Economic Development and Cooperation) through UNIDO's Industrial Development Fund, for the timeframe 2012-2016.

By way of background, the joint global UNIDO-UNEP Resource Efficient and Cleaner Production (RECP) Programme is based on a multi-pronged programmatically- and geographically-focused approach to scale-up and mainstream the application of RECP concepts, methods, techniques, technologies and policies in developing and transition countries in order to improve the resource efficiency and environmental performance of enterprises and other organizations, in particular small and medium sized operators in the manufacturing and associated sectors.

The aim of the Project on *Industrial Waste Minimization for Low Carbon Production* is to achieve step-reductions (as compared to incremental reductions) in the generation of industrial waste and by-products, including organic materials, as well as to foster their valorization. This serves the triple purpose of improving the local environment (less waste and waste water), mitigation of greenhouse gas (GHG) emissions (reduced energy consumption and reduced methane generation from waste) and economic benefits (resource productivity and possibly better product quality). This could require the introduction of new Environmentally Sound Technology (either as processing technology or for recovery of materials and/or energy), or might be achieved by improvements in management and supply chains or development of by-product businesses.

The first phase of this project, launched in 2013, focuses on the coffee and rice sectors in Cambodia, Colombia, Peru and Vietnam.

This report is one of five major deliverables based on the results of the activities conducted in each country for both sectors.

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Acknowledgements

This report has been drafted by Sofies under UNIDO's guidance with the financial support from the Swiss State Secretariat for Economic Affairs (SECO, Economic Development and Cooperation). Activities in each country have been conducted in close collaboration with the National Cleaner Production Centres (NCPCs).

The authors wish to thank the many stakeholders that have contributed to this project, as well as the companies who have shared their information and benefited from the cleaner production audits conducted under this project.

Executive summary

While rice makes up for most of the world's staple food, it is also a vital resource in terms of food security, employment and export revenues. However, because it is prone to price and production fluctuations, variations can affect large parts of the world's population. The constant grow in consumption and price asks for a higher productivity in order to avoid shortages.

Important fluctuations in prices occur, which are influenced by meteorological, technical, infrastructural and trading causes. As a consequence, not only are rice farmers and processors highly dependent on the weather and the supply of energy to sustain their production, fluctuations in price greatly affect their capacity to reinvest funds for the next harvest. Since price mechanisms will finally determine the income of the farmers and other workers, reliability and stability on prices are the basis for continued production and contribute to reduce the vulnerability of the rice sector.

The implementation of RECP schemes, such as valorization of rice husks for energy production, would equip workers of the rice sector with a sustainable and lasting strategy enabling them to be more independent towards fluctuations in energy supply, and therefore be less affected by dramatic changes in market prices. Also, with lasting problems in the financing of future crops, the integrated process offered by RECP would empower growers to invest on a sustainable basis.

However, rice husk and other rice by-products are generally under-used, and are regularly dumped or burned.

Research from this project in Cambodia, Colombia, Peru and Vietnam show that a maximum of 20 % of the rice husk produced is valorized at rice mills for the drying process, or for marginal use outside the rice mills. This means that there is potentially a huge untapped amount of renewable resource that could be systematically valorized.

This report is structured along three main parts.

Part I focuses on describing the rice processing chain, the different wastes that are produced and the environmental issues that are related. A review of RECP applications for the valorization of theses wastes is presented and more detailed project fact sheets are presented in the separate annex document[1].

Part II discusses the specific context of the countries in which the investigations were conducted. Understanding the legal, policy and financial frameworks, as well as the structure of the market, availability of technologies or functioning of the electricity market are as many variables that will have a direct incidence on the possible implementation of RECP projects in the rice sector.

Part III presents the aggregated results from the cleaner production assessments conducted at company level. RECP indicators such as energy consumption or waste generation are presented and compared between countries. A detailed presentation of the RECP indicators at company level is available in the separate annex document (annex C). The type of CP options that are recommended are presented and discussed.

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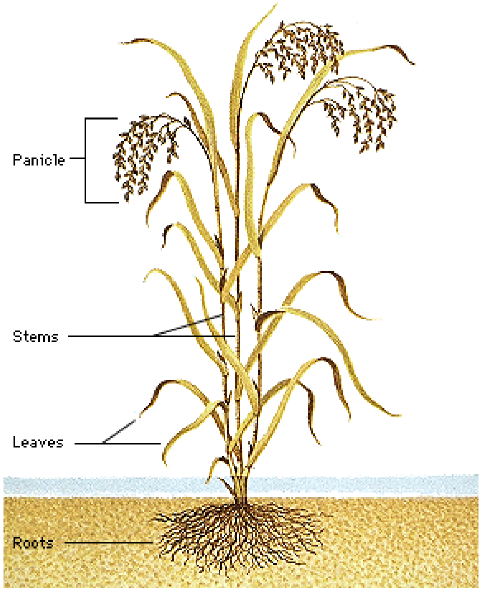
[1] Annex document : Detailed description of RECP Solutions in the Rice sector

Part 1. Industrial processes

1.1 Botanical and agricultural aspects

1.1.1 Rice characterization



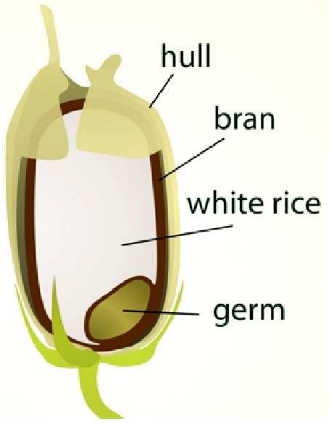
Rice (Oryza) is a tropical cereal and the staple food for almost half of the world population.

Currently, two rice species are widely cultivated: *Oryza Sativa* originating from Asia and *Oryza Glaberrima* originating from Africa. *Oryza Sativa* is the most cultivated species in the world and is subdivided into two groups: *Japonica* (round grains) and *Indica* (longer and thinner grains).

The plant consists of several panicles (ears) that flower and produce rice grains: 100-150 seeds per panicle. Depending on its area of cultivation, rice can yield 1 to 3 crops a year (Accueil et culture, CIRAD, INRA).

Table 1 Properties of rice compiled from PROTA database

Rice characteristics	
Size of the plant	0.6-2m (up to 5m for floating species)
Minimal temperature required for growth	20°C
Area of cultivation	From equator to 45°lat
Altitude of cultivation	Up to 1900m
Water needs per growth cycle	1700-2500 mm
Duration of cultivation cycle	Mean: 120 days
Global rice yield	4 t/ha (Calpe, 2007)



The rice grain is composed of several parts: the kernel (endosperm), the germ, the bran, and the hull/husk (a cellulose layer). Paddy rice is the rawest form of rice as it includes the hull, the bran and the germ, and is not eddible.

Brown rice, also known as cargo rice, is obtained by removing the hull. White rice, which requires further processing, is obtained by removing the hull, the bran and the germ.

1.1.2 Rice cultivation

Because rice needs significant amounts of water to grow, different cultivation methods have been developed to manage the supply of water, the local water regime and the various constraints related to water. These methods include deepwater, rainfed lowland, irrigated, and upland cultivation. Each of these cultivation methods requires the exploitation of different varieties of rice in order to maximize production yields.

In order to maintain a sufficient supply of water, irrigated and rainfed rice are cultivated in bunded fields (i.e. fields that are enclosed by berms to keep a constant high water level). The irrigation system allows for better control of the water supply as it can be conveyed by channels. On the other hand, the absence of water-channeling in the production of white rice is called the “plot-to-plot” method. Rainfed lowland rice fields are alimented by rainfall and runoff water. Deepwater rice fields are located in areas subject to flooding where the water level can rise up to 5m. The variety of rice employed in such areas is called floating rice with reference to its capability to grow even when water levels rise. The following figure illustrates the morphology of the different types of rice paddy.

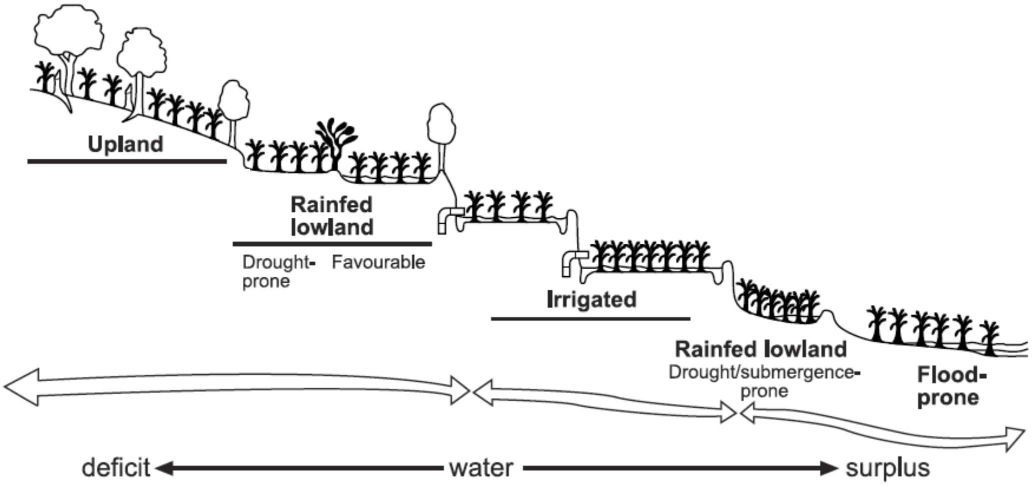


Figure 1 Types of rice cultivation (Gupta, 2004)

The following map illustrates the distribution of these methods throughout the world.

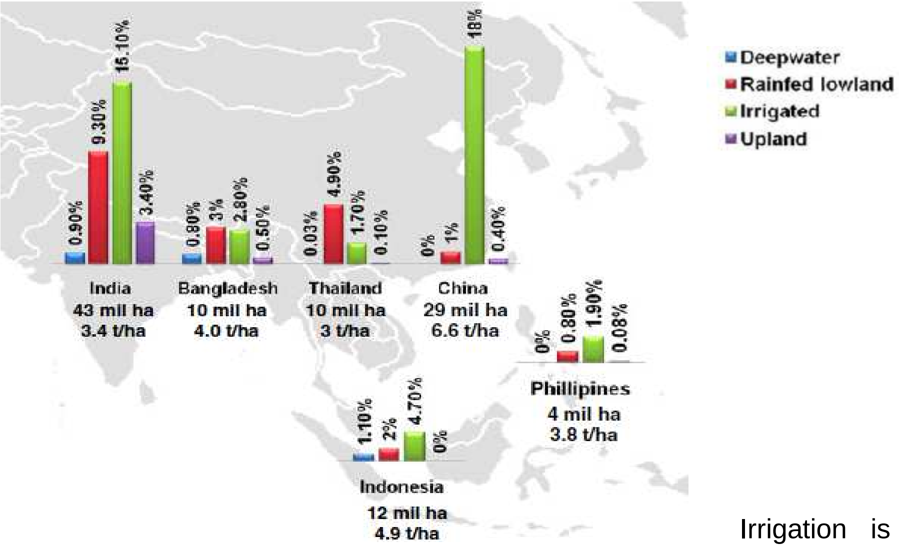


Figure 2 Distribution of rice grown in deepwater, rainfed lowland, irrigated land, and upland. (Mackill, 2010)

Irrigation is the most widely used method of cultivation and accounts for 75% (IRRI, 2009) of the world's rice production. It is an intensive technique that produces the highest yields (around 10-15 t/ha per year (IRRI, 2009)) and is also the most expensive.

Regarding the seeding method, rice can be either directly sowed onto the field or grown in a nursery before being transplanted into the field. Similar yields can be obtained from both methods as the plant compensates for reduced seed density by greater tillering (i.e. the formation of aboveground shoots) in the case of transplantation.

1.1.3 Rice harvesting

Figure 3 Manual threshing in India

Harvesting can be done manually or mechanically. Manual harvesting is the most labor-intensive method as it generally takes around 80-240 labor hours per ha (Mejía).

The first step consists of cutting the stalks (long stalk cutting) or the panicles (panicle reaping) with tools such as knives. Once harvested, the rice grains (paddy) are separated from the panicle and the stalk by threshing. Threshing can be performed manually by hand beating or by using a treadle thresher, which is more efficient. Threshing can also be done mechanically using a threshing machine.

Figure 4 Mechanical thresher in Myanmar

The last method combines the collection and harvesting steps by using a combine harvester. This is the least labor-intensive method but also the most expensive since it requires a massive initial economic investment.

When the stalks are left on the field, they are generally disposed of by burning.

Figure 5 Combine harvester in Japan

1.2 Rice processing

Three methods of rice processing are described in the following section:

- Regular white rice processing
- Parboiled rice (partially boiled rice) processing
- Instant rice processing

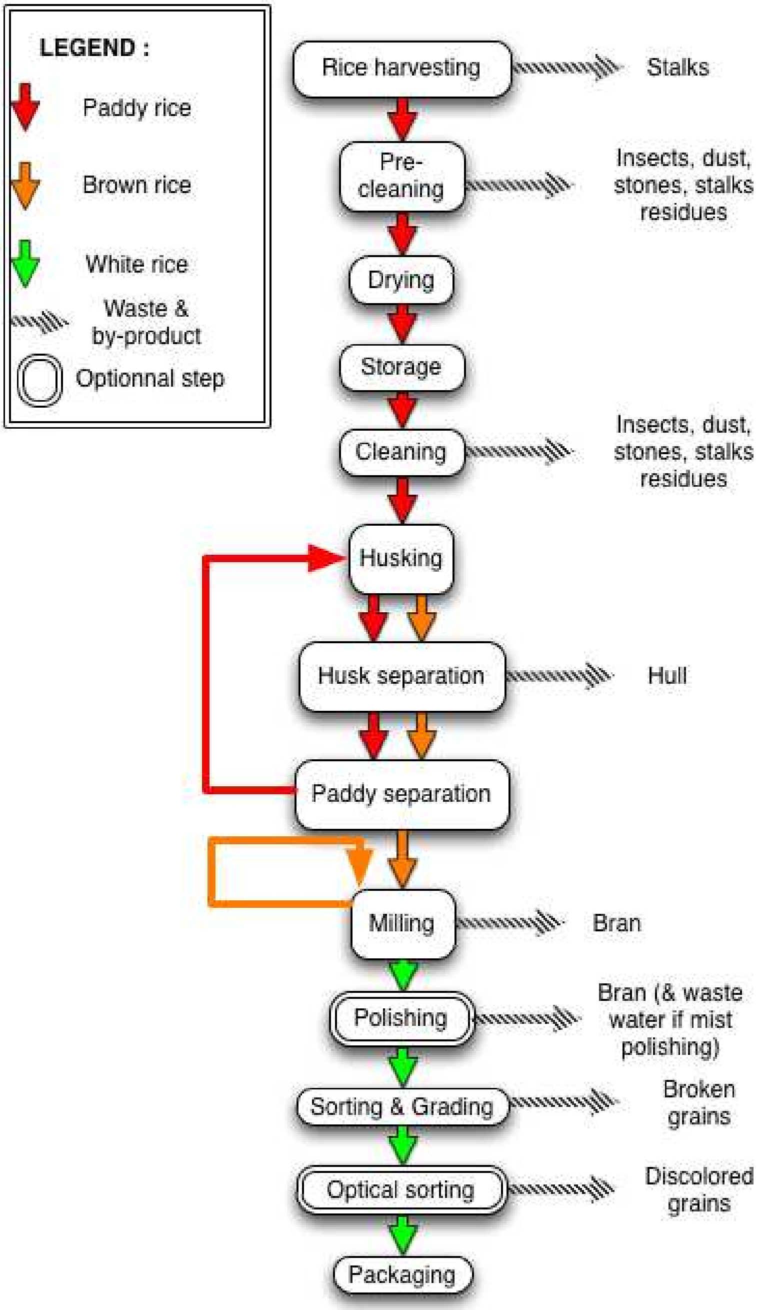
Their main characteristics are detailed in the following table.

	Parboiled rice	**Instant rice**
Main distinctions from regular white rice	Cooking step (steaming) before husking	Cooking step after husking and milling
Effect	• Gelification of starch in the kernel • Transfer of nutrients from the husk to the kernel • Swelling of the grain by water absorption	• Gelification of starch in the kernel • Generation of micro-cracks in the kernel
Advantages	• Nutritional qualities improved • Grain strength improved, better storage, better preservation • Milling yield improved • Reduction in the amount of broken kernels during milling • Better by-product quality • Better cooking quality (no stickiness) • Well adapted to use in frozen conditions since the grain strength is improved	• Reduction in cooking time
Disadvantages	Modification of the rice aspect: yellow color Strong odor due to fermentation during soaking for paddy parboiling	Reduction of rice quality

It is interesting to note that parboiling can also be performed on brown rice (after husking), which provides similar results to paddy parboiling. However, this method is generally less frequently employed than paddy parboiling.

1.2.1 Process flow diagram

Depending on the designated users of the rice, processing can differ considerably. Usually, the rice destined for exportation has a high level of processing to satisfy high quality requirements. In general, to further satisfy high requirements, its final packaging is realized in the country of consumption. On the other hand, rice destined for the domestic market has lower quality requirements and its packaging is completed at the processing site. The processing of rice dedicated to the domestic market is often simplified, as husking and milling are performed in one single step. The following process flowcharts mainly concern the cases in which the rice is destined for exportation.



1.2.2 Processes description

I. Pre-cleaning

In order to remove the impurities such as stones and insects that may have mixed with the paddy, it can be passed through filters that separate the coarse impurities from the paddy. It can be also passed through filters equipped with meshes to eliminate finer impurities such as sand. Also, a fraction of light impurities can be removed using winnowing, as wind will allow light impurities to be blown out of the paddy.

Cleaning can also be done mechanically by a succession of steps using filters, blowers and gravimetric methods (such as shaking tables), especially in the case where high standards of purity are required. An example of this type of system is illustrated in Figure 7.

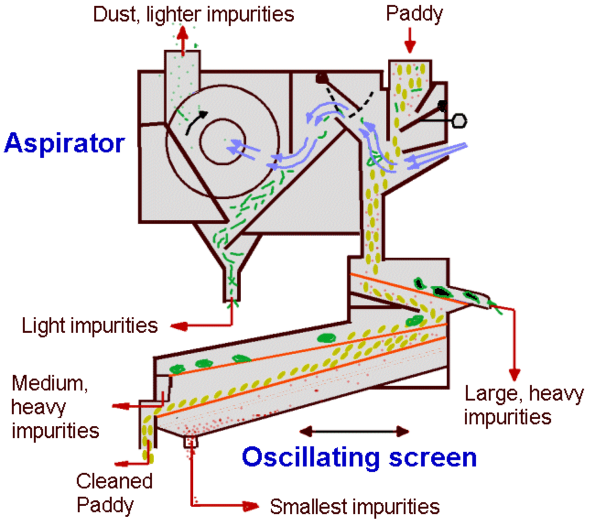


Figure 7 Paddy cleaner, source : (IRRI, 2009)

II. Drying

Drying is a paramount step in rice processing. It lowers the moisture content (MC) to 13-14 % (IRRI, 2009), a level that allows optimal storage of the rice by stopping (or at least slowing down) the chemical and biological reactions that could degrade the cereal due to moisture. The drying step should be realized within 24 hours following the harvest in order to preserve the quality of the rice and avoid its degradation.

Different drying methods are used, depending mostly on the technological and economic capital available. The different methods are classified in the following chart[2].

The easiest method of drying is called field drying. It consists of leaving the harvested plants (panicles and straws) in piles on the field. It is basically a cheap process, but can lead to substantial grain degradation due to rodents, insects and other pests.

Open sun drying is another method that does not require industrial machinery. Rice grains are simply spread on the ground (e.g. pavement) to be heated by the sun. This low-cost

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[2] As for the solar energy dryers, more details can be found in the following annex of this document: Detailed description of RECP Solutions in the Rice sector - Project Identification Form n°11 and 12.

method is labor intensive but can at the same time produce good quality grain. However, just like field drying, this method is very dependent of atmospheric conditions as the exposure of the grain to rain could result in significant damage. On average, one sunny day or two cloudy days are generally required to lower the MC to 14% (Agnes Chupungco, 2008).

Mechanical or industrial drying methods are split into 3 groups: fixed bed drying, recirculation drying and continuous flow drying. Unlike field and sun drying, industrial methods are independent of atmospheric conditions and sunlight intensity, therefore presenting a substantial advantage.

Fixed bed drying is similar to sun drying except for the heat source. Rice grains are spread over a perforated surface through which air is forced.

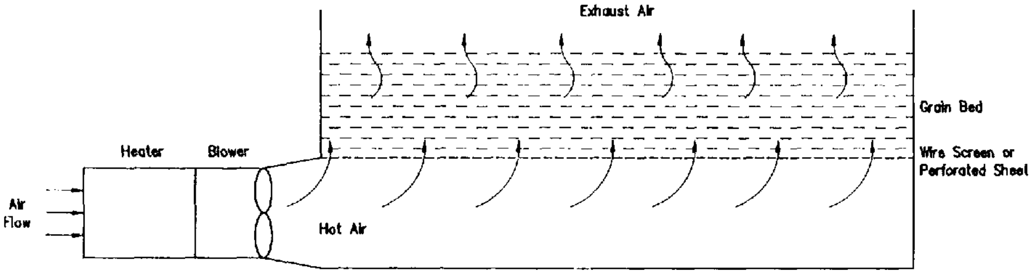


Figure 8 - Flatbed rice dryer scheme - FAO

In order to improve the process, the grains should be mixed regularly to even the drying. This is the simplest and cheapest industrial method.

The use of recirculation drying beds can eliminate the disadvantages of exhaust air. However, this system requires skills to be properly run and is also more expensive. Figure 9 describes the general operation of such a system: the paddy is heated from below, then circulated to the top of the machine using an auger, then relapsed to the bottom to be re-heated in a circular motion. However, this process generates dust that needs to be evacuated in order to avoid the gathering of dirt. In addition, the system must be carefully maintained as moving components can easily be subject to wear and abrasion.

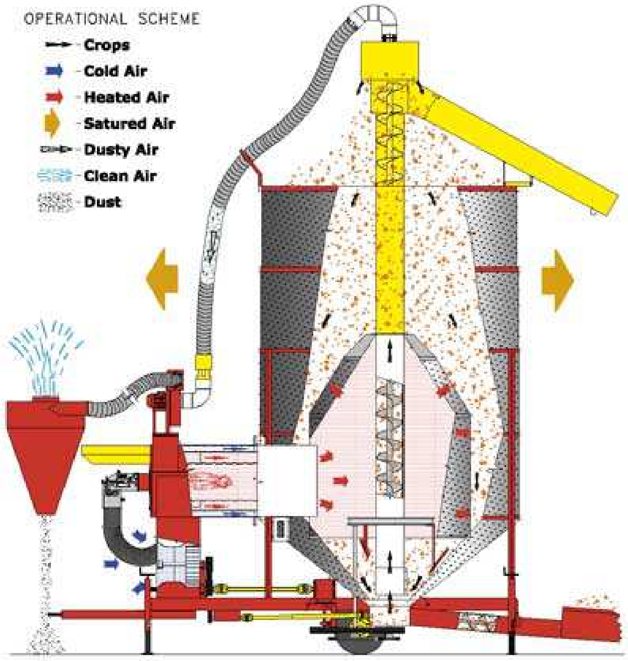


Figure 9 - Pedrotti recirculating grain dryer

Fixed bed drying and recirculation drying are batch systems, meaning that the drying is not done continuously but repeatedly using limited quantities.

Continuous flow drying is preferred when processing larger amounts of paddy. However, it requires significant technological and financial capital and is complicated to operate.

III. Storage

The paddy can be stored using bags that are organized in stacks or in bulk using silos, for example. One of the main problems of storage is the management of moisture levels since atmospheric moisture is often higher in tropical areas than the paddy's desired moisture content. One of the solutions is to hermetically store the grain in order to prevent its humidification using PVC containers, for example.

Figure 10 - Paddy storage stacks in India

At the end of the storage phase, the grains undergo a cleaning process, following the same steps that the one describe in the pre-cleaning section (section I).

IV. ***Parboiling***

As mentioned earlier, parboiling is performed in 3 steps: soaking, steaming and drying. It can be achieved either in artisanal fashion or industrially.

The grains are first soaked in water (3-4 hours in hot water or 1-2 days in cold water). Once the grains have absorbed a sufficient amount of water they are then steamed.

Finally, the grains undergo a drying step using the processes described in the previous chapter.

Figure 11 Parboiling unit in Bangladesh, source: (Poritosh Roy, 2006)

V. ***Husking***

Husking consists of separating the hull (husk) from the rest of the rice grain. Different systems can be used for husking: disk huskers or rubber roll huskers.

The disk husker consists of two abrasive disks placed parallel to one another with the bottom disk spinning horizontally. The paddy is injected at the top and is husked between the two disks as illustrated in Figure 12.

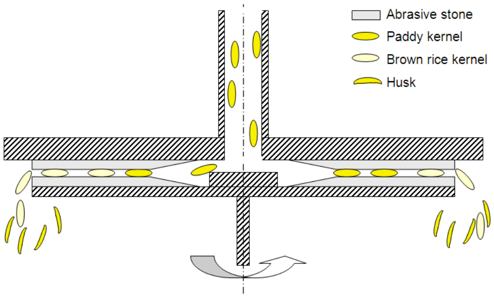


Figure 12 Disk husker, source: (IRRI, 2009)

This system can support large volumes of paddy, requires moderate investment and is rather easy to operate.

The rubber roll husker (Figure 13) is composed of two rubber surfaces, such as rubber stones, that spin at different speeds in order to loosen the hull. This system has a similar loading capacity to that of the disk husker.

VI. ***Husk aspirator***

Figure 13 Rubber roll husker, source: (Sage V Foods)

The product resulting form husking is a mix of brown rice, paddy rice and husks. A husk aspirator using weight properties first removes the hulls from the mix.

VII. ***Paddy separator***

Figure 14 Paddy tray separator source: (IRRI, 2009)

Once the hull has been separated form the rest of the grains, the paddy that has not been husked is separated from the mix by the paddy separator before being re-loaded into the husker. Three types of paddy separators exist: screen separators, tray separators and compartment separators. Screen separators are more often dedicated to small loads of grains whereas tray and compartment separators are employed for large quantities of rice as seen in industrial processing.

Screen separators do not need a complex mechanical system; the grain is simply passed through screens to separate the paddy portion from the brown rice.

Tray separators are composed of a sloped table that oscillates so that the mix of paddy and brown rice loaded at the bottom will separate. The brown rice will move up faster than the paddy rice.

Compartment paddy separators work on the same principle as tray separators, but instead of having one surface of oscillation, these separators are composed of several zigzag compartments in which the mix of paddy and brown rice is loaded. The brown rice goes up while the paddy rice goes down, as illustrated in the following figure.

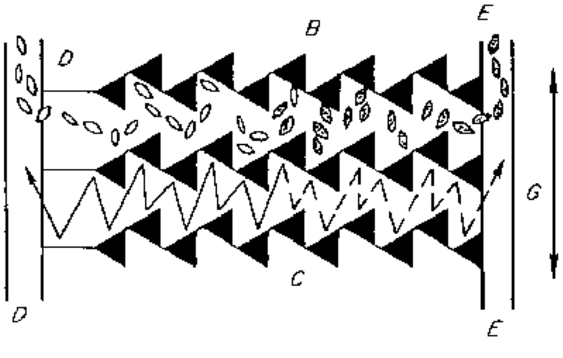


Figure 15 Compartment paddy separator, source: (FAO, 2012)

VIII. ***Milling & Polishing***

Figure 16 Abrasion machine, source: (IRRI, 2009)

The goal of milling is to remove the bran layer in order to obtain white rice.

Milling can either be done by abrasion or by friction. Abrasion is rather compatible with long rice varieties as the pressure applied on the brown rice is less intense.

An abrasive disk spinning against an immobile wall performs abrasive whitening.

Friction whitening eliminates the bran via friction between the rice grains themselves; it is composed of a rotating cylinder with a metal screen as the external wall containing the brown rice.

In order to avoid rice cracking, which can be the result of high temperatures in the machines, the rice grains undergo a series of abrasion/friction steps.

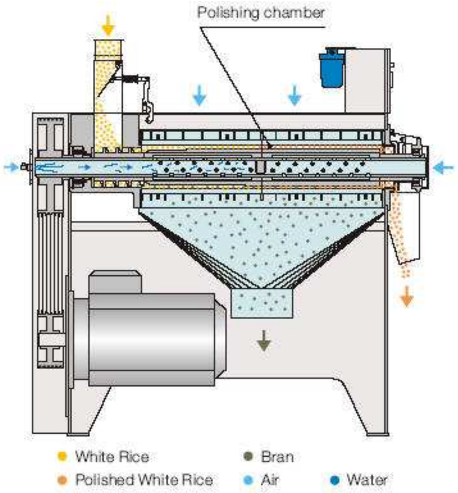


Figure 17 Mist polisher, source: (Rodriguez, 2011)

The resulting bran powder is removed by blowing air into the machines, which also helps cool down the rice grains.

A subsequent polishing step can be added depending on the required rice quality. Polishing helps to fully remove the bran residues from the rice kernels.

It can be similar to the abrasion process whitening but less intense. Mist polishers apply mist (water) on the kernels as illustrated in Figure 17.

IX. One-step domestic rice milling

Single step machines (called single step rice mills or compact rice mills) are still sometimes used to produce rice destined for the domestic market. This machine combines cleaning, husking and milling. It can only process small amounts of paddy at a time and presents significant breakage yields: the rate of milled rice recovery reaches 53%. Its use is therefore not recommended.

X. Sorting/grading

Once the rice has been husked and milled, the obtained mix is composed of broken grains, immature grains not suitable for consumption (presented by a darker color), grains of different sizes etc. Therefore, the mix has to be sorted in order to be suitable for trade.

First, the broken grains are removed from the mix using sifters. This process consists of passing the grains through a succession of screens.

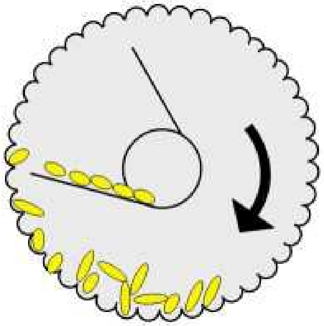


Figure 18 Length grader operation description, source: (IRRI, 2009)

Once the broken grains have been removed, the rice can be sorted by grain size using length graders. These machines are composed of a rotating cylinder with internal walls composed of small indents. Once the rice has been loaded into the cylinder, the rotation makes the smaller rice grains move up while the longer ones stay below. The smaller grains are then evacuated from the cylinder. The size of indents determines the length of the grains selected.

Rice grains can also be sorted out according to their diameter using a grooved rotating cylinder that manages the grains of desired size.

I. *Optical sorting*

An optical sorting step can be added, if required, in order to remove the discolored rice grains.

Figure 19 illustrates how it operates. The rice grains are loaded and individualized by the machine. They are then analyzed by a camera that can detect discoloration. If a discolored grain is detected, it is ejected from the mix by compressed air.

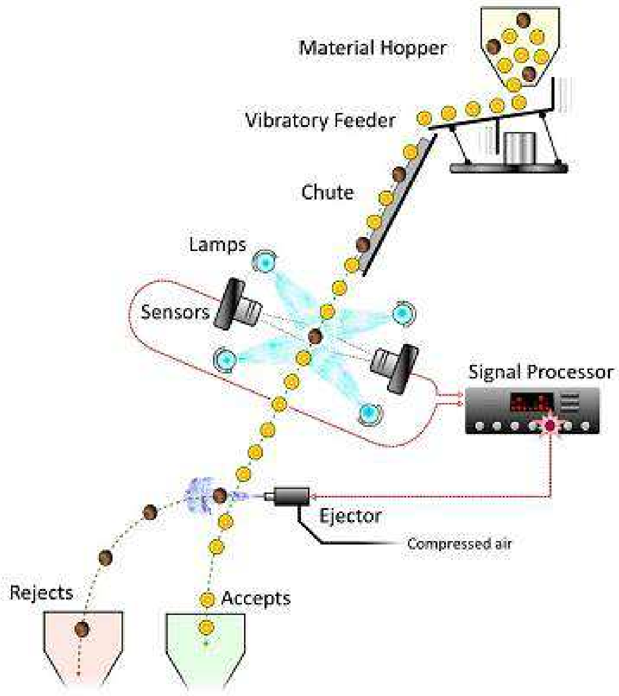


Figure 19 : Optical sorter operation scheme – (Satake USA, 2012)

II. ***Load-out/Packaging***

Rice can be loaded into bags using a bagging machine, which simply fills and seals the bags.

Figure 20 : Ruili bagging machine – (Made-in-China.com, 2013)

1.3 Major environmental concerns of rice processing

1.3.1 General impacts

It appears that the major impacts on greenhouse gases emissions resulting from rice production stem from paddy cultivation. In fact, as most of the fields are irrigated or flooded (lowland cultivation), this induces long submersion times and the development of anaerobic organisms that produce an important amount of methane and nitrous oxide. As an example, a Life Cycle Analysis (LCA) performed on irrigated rice (integrated field processing, water needs for irrigation, paddy processing etc.) in northern Italy reported that field emissions account for 68% of the global warming potential (Gian Andrea Blengini, 2008). According to the same study, the conversion from lowland cultivation and irrigated cultivation (by submersion) to upland cultivation (irrigated, using sprinklers or furrows) could reduce the impacts on greenhouse gas emissions by 50%. Another LCA performed in Thailand indicates that 95% of the global warming potential is a result of agricultural cultivation (Sakaorat Kasmaprapruet, 2009).

In addition, significant impacts are also generated as a consequence of the use of pesticides, fertilizers, etc. during the cultivation phase.

However, since this current project is focused on rice processing, the impacts of paddy transformation will also be detailed.

1.3.2 Impacts of paddy processing

Comparison of white rice and parboiled rice processing

The impacts of paddy processing are intrinsically dependent on the methods used during transformation. According to the type of energy used - fossil fuels such as diesel, electricity from the local grid or renewable energy such as solar energy - impacts can vary considerably. In order to be able to rigorously analyze the environmental impacts of rice processing, we should examine its consumption of resources such as energy and water, as well as its production of waste and by-products.

The following schemes present the resource consumption, waste and by-product production for the processing of 1 ton of paddy resulting in parboiled rice and white rice. This is a rough analysis that does not take into account field cultivation, the construction of the plant, the maintenance of machinery, etc. Additionally, it does not mention the production of 1 ton of stalks as a by-product of the production of 1 ton of paddy.

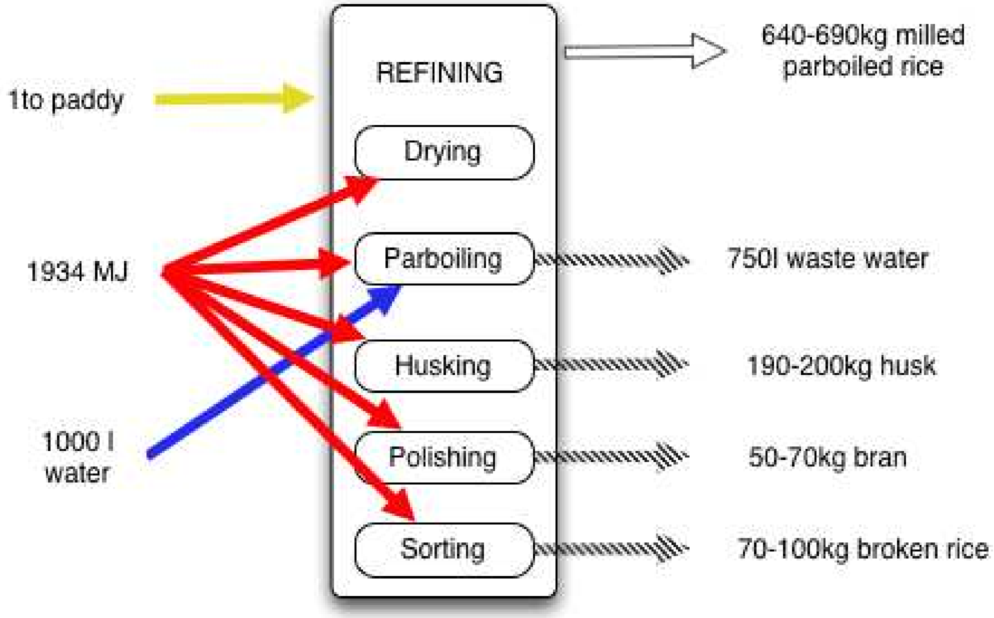


Figure 21 Consumption of energy and waste production of parboiled paddy, compiled from: (Gian Andrea Blengini, 2008) and (IRRI, 2009). The arrow size is not representative of flux quantities. The yield of milled parboiled rice obtained is taken from the production of white rice, thus, these results should be treated with caution since the parboiling step improves the milling yield and reduces the amount of broken grains.

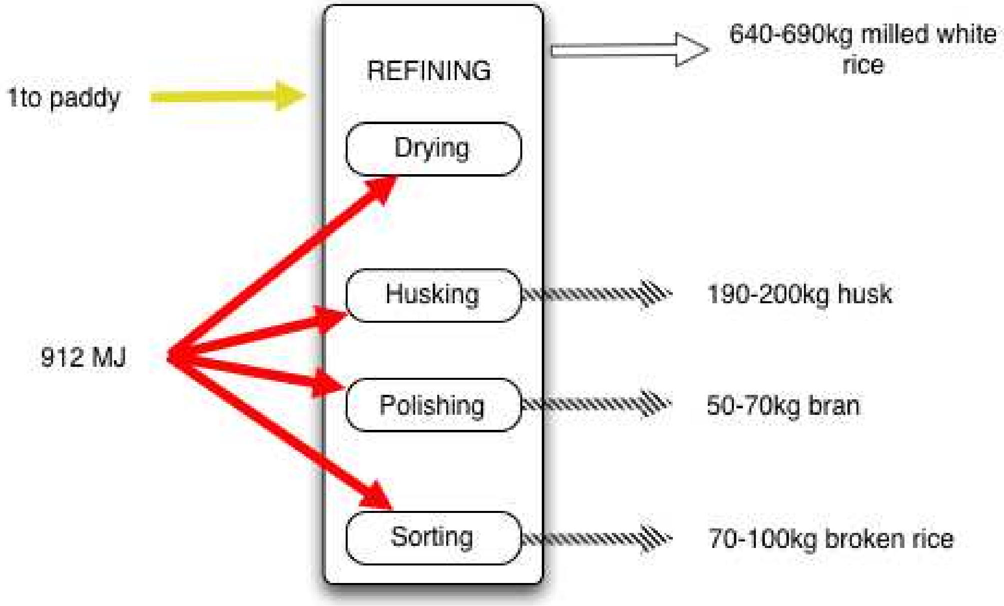


Figure 22 Consumption of energy and waste production of white rice, compiled from: (Gian Andrea Blengini, 2008) (IRRI, 2009). The arrow size is not representative of flux quantities.

Parboiled rice appears to be a more energy demanding process and uses an important amount of water. In addition to that, the wastewater produced is highly polluted[3]

Impacts by processes

According to an LCA performed in Thailand, the drying step is the most energy demanding of all the processing steps (Sakaorat Kasmaprapruet, 2009).

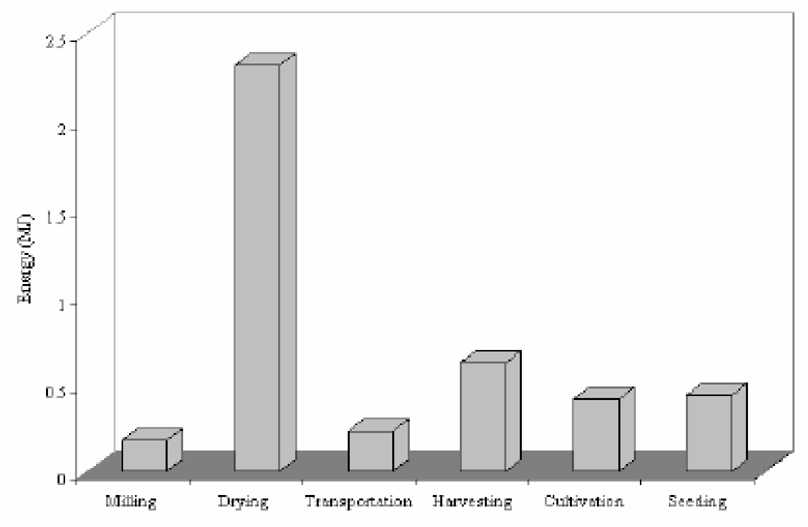


Figure 23 Energy demand of white rice processing in Thailand, source: (Sakaorat Kasmaprapruet, 2009)

1.3.3 By-product use

The aim of this chapter is to recap the various valorization possibilities of rice by-products. By-products resulting from rice processing can be used either as energy sources or for other purposes such as fertilizer, construction materials, etc. The following figure summarizes the conversion routes of biomass to energy.

Rice processing by-products include stalks, hull (husk), bran, and broken grains.

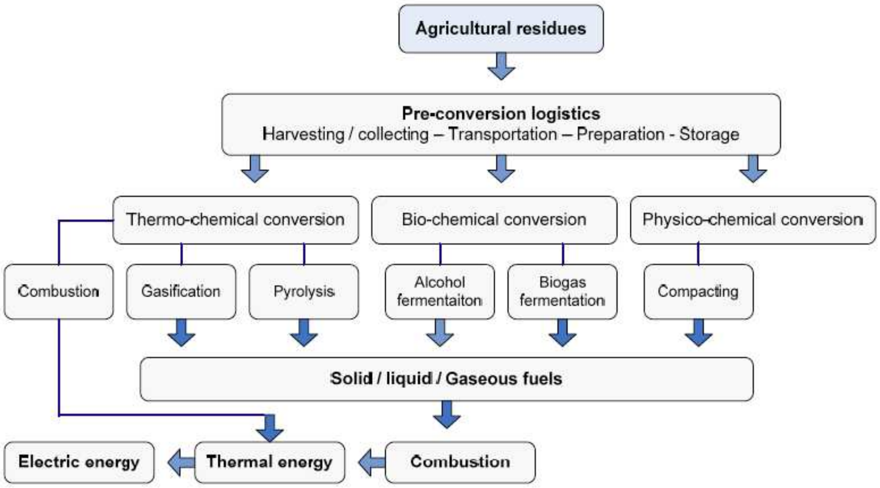


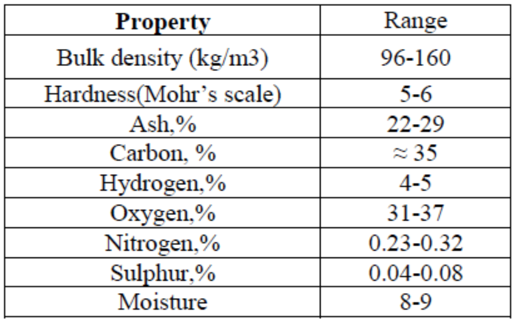
Figure 24 - Conversion routes of agricultural residues to produce energy, source: (M. Barz, 2011)

Stalks

As mentioned above, the production of 1 ton of paddy results in the production of 1 ton of stalks that can be collected and used to produce bioethanol. However, the production of bioethanol from rice stalks is not very common since its cellulosic characteristics make its conversion into bioethanol rather difficult. The gasification of rice straws (that can be mixed with other materials) is more common. Rice stalks can also be used to produce paper and items such as rope.

Hull

The hull is obtained after husking the grain. It is mainly used for energy production purposes due to its good calorific value. It has a low bulk volumetric mass (100-150kg/m^3), good insulation properties and contains an important fraction of silica. Rice hulls can be burned, thus producing husk ash that contains around 85-90% of amorphous silica (IRRI, 2009). Sometimes, rice hull is also gasified. This process can deteriorate the machinery (because of the significant concentration of silica in the ash) and thus requires proper maintenance.



Property	Range
Bulk density (kg/m3)	96-160
Hardness(Mohr's scale)	5-6
Ash,%	22-29
Carbon, %	≈ 35
Hydrogen,%	4-5
Oxygen,%	31-37
Nitrogen,%	0.23-0.32
Sulphur,%	0.04-0.08
Moisture	8-9

Figure 25 Characteristics of rice husk, source: (A.Kumar, 2012)

Bran

Bran is obtained during the milling and polishing steps. The bran obtained by polishing often contains endosperm residues (residues of white rice) making it a good filler for animal feed. Its nutritional value (significant amount of B-vitamin etc.) makes it suitable also for pharmaceutical use or to produce vegetable oil. Once the oil is extracted, the fat-free bran can be reused in animal feed. Raw bran contains around 12-18% of oil whereas parboiled bran contains around 20-28% of oil (Directorate of Rice Development, 2001).

The following table details the various utilizations of the rice by-products and was put together in the most comprehensive manner possible, given the available information.

By-product	**Use**
Hull (husk)	Energy source: • 1kg husk (10% MC)→LHV=14.50 MJ (T.Suramaythangkoor, 2009) • Rice husk briquettes (Assureira E. , 2002) (Kishore, 2003)
	Other: • Litter materials

	• Animal feed • Soil fertilizer additive • Sorbent in environmental remediation • Carbon/silica composite (S.Kumagai, 2009) • Source of silica (J.P. Nayak, 2010) (S.Chandrasekhar, 2003) • Component of refractory material (B.I.Ugheoke, 2006)
Burn husk **(A.Kumar, 2012)**	• Partial cement replacement (UNFCCC, 2005) (K. N. Farooquea, 2009) • Steel additive (A.Kumar, 2012) • Component for refractory materials (K. N. Farooquea, 2009) • Source of amorphous silica (S.Chandrasekhar, 2003)
Carbonized husk **(Phillipine Rice Research Institute (PhilRice), 2005)**	Energy source: • Charcoal (Directorate of Rice Development, 2001) (S. Maiti, 2006)
	Other: • Soil additive • Activated carbon
Bran	• Bran oil (M.Ghosh, 2005) • Medicinal use • Growing medium for probiotic bacteria (P.Saman, 2011)
Defatted bran	• Animal feed (S.Gadberry) • Baking (M.Shaheen, 2005) • Soil fertilizer
Broken rice (brewer rice)	• Animal feed • Food making purposes (noodles etc.)
Stalks **(M. Barz, 2011)**	Energy source: • 300-350L of bioethanol can be produced out of 1 t of stalks • 1 kg rice stalks (11% MC)→ LHV=13.68 MJ (T.Suramaythangkoor, 2009)
	Other: • Animal feed filler (D.J.Drake, 2002) • Litter materials • Paper • Items (hats, shoes, baskets etc.)

Some of the possible by-product valorizations listed above are explored in more detail (according to the quality of available data on the subject) in the detailed description of RECP Solutions in the Rice sector, in the separate annex of this document. The energetic valorization of rice by-products is more detailed with more available information on the subject. Further research should be done on non-energetic ways of valorizing rice by-products such as cement replacement, production of refractory material, animal feed, medicinal use of rice bran, etc.

1.4 RECP applications overview

This following section presents a variety of projects implemented in various locations, using a wide array of technologies and by-products.

The majority of RECP applications in the rice-processing sector concern an energetic valorization of husk or straw, and a few aim at improving the efficiency of the rice processing.

Tough several of these projects are supported by international cooperation agencies, a few are promoted by private investors, thus demonstrating the economic interest in such technologies.

The outcomes are generally twofold, allowing for the reduction of fossil fuel consumption whilst solving a waste management problem.

The table below presents a general outline of the different projects and, while a detailed description of the projects can be found in a separate annex (Detailed description of RECP Solutions in the Rice sector).

RECP Projects	**Project title**	**By-product use**	**Technology**	**Outcome**	**Country**	**Stakeholders**	**Comments**
1	ROI-ET Green Power Project	Husk	Steam boiler to generate high-pressure to drive a steam turbine	Reduction of fossil fuel imports Reduction of pollution and greenhouse gases emissions Elimination of rice processing wastes	Thailand	Energy/electricity producers	High investment cost Rice husk supply must be flowing and maintained
2	Industrial energy efficiency project: Ving Cheang Rice Company	Husk	Gasifiers and fuel generators to produce electricity and hot air	Reduction of fossil fuel consumption by 70% Reduction of GHG emissions of 510t/y Improvement of rice quality and milling yield	Cambodia	GEF-UNIDO, National Cleaner Production Office Cambodia, Nicoline Investment Co. Ltd	Cambodia is dedicated to becoming an important stakeholder of rice exports in future years Payback period: 30 months
3	Automated carbonization of rice husk	Husk	Automated carbonization systems (ACS)	Elimination of rice husk Production of Carbonized Rice Husk (CRH) and Organic Fertilizer (OF)	Philippines	Oliver Enterprises, Filipino and Japanese joint ventures, Philrice	Payback period: 24 months (projected), 36 months (effective)
4	Program for Development and Establishment of Soft Cellulose Utilization	Straw	Production of bioethanol	Elimination of rice straws Production of bioethanol	Japan	Ministry of Agriculture, Forestry and Fishery of Japan	Estimated 1.8 m3 of bioethanol could be produced out of rice straw, which in turn decreases

	Technology						independence towards fossil fuels
5	10 MW Biomass based independent power project of Jalkheri Power Private Limited	Mostly husk, but also straw, wood chips, cotton waste, etc.	10 MW condensing turbine	Reduction of fossil fuel consumption Elimination of by-products and waste	India	Jalkheri Power Private Ltd (JPPL), Punjab State Electricity Board (PSED), Ecoinvest Carbon SA (from Switzerland)	Collaboration between local, regional (governmental) and international actors
6	25 MW Jiangsu Rudong Biomass Power Generation Project	Mostly straw, husk occasionally	25 MW steam boiler	Reduction of fossil fuel consumption Elimination of by-products and waste	China	Jiangsu GuoXin Rudong Biomass Power Co. Ltd., Arreon Carbon UK Ltd.	High surplus of biomass available resulting from production
7	Angkor Bio Cogen Rice husk power project	Husk	2 MW power plant adjacent to a rice mill Extra steam produced for paddy drying	Reduction of fossil fuel consumption Elimination of by-products and waste Technology transfer (it is the first project out of rice husk in Cambodia)	Cambodia	Angkor Bio Cogen Co. Ltd., Punjab State Electricity Board (PSED), Mitsubishi UFJ Morgan Stanley Securities (through Japan), Swedish Energy Agency	Surplus of available biomass Great capacity for technology and know-how transfer
8	Benefits of improved rice husk combustion in small scale mills in Bangladesh	Husk	Husk boilers	Reduction of GHG emissions Elimination of by-products and waste Improvement of combustion efficiency	Bangladesh	Natural Resources Institute (UK), Department for International Development (UK), The Energy and Resource Institute (TERI)	Hima cement invested in coffee production in exchange fro husk to run the plant
9	Benefits of improved rice husk combustion in small scale mills in Bangladesh	Husk	Rice husk briquetting	Better product quality Reduction of the account of screws used Reduction of GHG emissions	Bangladesh	Natural Resources Institute (UK), Department for International Development (UK), The Energy and Resource Institute (TERI)	Only a marginal amount of rice husk is used for briquetting
10	Partial substitution of fossil fuels with biomass in cement manufacture	Husk	Husk burners	Reduction of fossil fuel consumption	Uruguay	Compania Uruguaya de Cemento Portland SA (CUCPSA), Cementos Molins Industrial SA (Spain), Corporacion Uniland SA	Surplus of available biomass in the region, with traditionally dumped and burning of rice husk
11	Two-stage grain drying in the Philippines	-	Two-stage grain drying technology	Improvement of rice grain quality Reduction of fossil fuel consumption	Philippines	Australian Center for International Agricultural Research (ACIAR), Philippine Council for Agriculture, Forestry and Resources Research and Development	Improvement of rice quality while at the same time avoiding rice losses
12	In-store grain drying in China	-	In-store grain drying technology	Reduction of fossil fuels consumption	China	Australian Center for International Agricultural	Improvement of rice quality while at the same time avoiding

	Elimination of waste	Research (ACIAR), State Administration of Grain (China), Chengdu Grain Storage Research Institute China	rice losses

1.5 RECP synthesis

1.5.1 Main transversal bottlenecks

After analysis of several implemented projects in various regions, a few transversal bottlenecks and key success factors clearly stand out, and are illustrated in the following table.

	Main transversal bottlenecks	**Key success factors**
All projects	• Problems with accessing financing and financial stability • Lack of skills and manpower • Legislation and national standards not adapted to local rice mills • Developed technology not suited to project scale, local conditions, material and skills availability	• Variety and stability of financial support for the investment phase, financing through CDM • Setting up of capacity-building programs, sensitization to RECP benefits (insisting on economy & health benefits) • Strong government support • Development of technology adapted to local skills, and machinery availability • Economic viability of the proposed technology, low cost technology
By-product to energy projects	• Variation of by-product quality (due to inappropriate storage, for example) • Increase of wear and abrasion of machinery using rice husk and straw instead of fossil fuels (due to high silica content) • Increase of by-product price due to by-product to energy projects development • Lack of electricity demand outside the milling hours (night time). • Difficulty to feed power into the national grid.	• Importance of partnerships (with local mills, for example, to ensure by-product supply): integration of the local stakeholders and the government • Integration of local stakeholders and government bodies.

1.5.2 Process-oriented prioritization

In accordance with this research, it appears that it is relevant to implement RECP interventions at the processing stage, as it is a high energy-demanding phase of rice production. In addition, the majority of by-products are produced during this phase.

Such interventions comprise:

- Storage improvement (combination of storage and in-store drying)
- Production of electricity and heat from rice husk and stalks
- Valorization of extra heat produced for the drying of
- Cogeneration of electricity from rice husk and stalks and steam dedicated to parboiling

- Improvement of the drying and parboiling step using more efficient machinery
- Valorization of rice husk in cement production
- Production of rice husk briquettes for small-scale mills

1.5.3 Projects to investigate

Although the majority of projects identified through the review of case studies are mostly focused on energetic valorization of rice by-products, the following areas deserve further investigation:

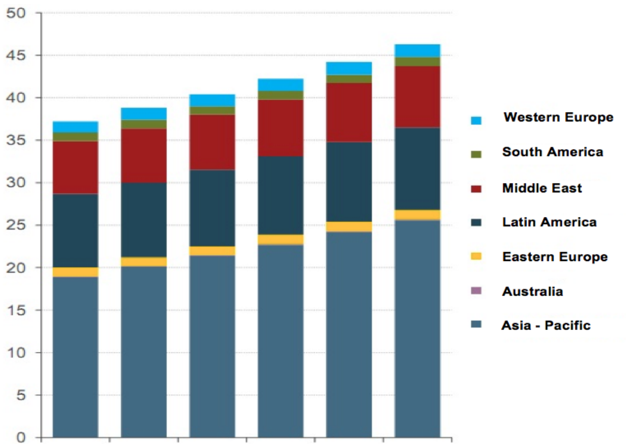
- Treatment of wastewater generated from parboiling.
- Reduction of water consumption for parboiling
- Improved solar paddy drying
- Valorization of rice husk to produce refractory material, steel additives and silica
- Valorization of rice bran (which seems quite commercially developed although few bran valorization projects are well documented)

Part 2. National Contexts assessment

2.1 The Rice sector in general

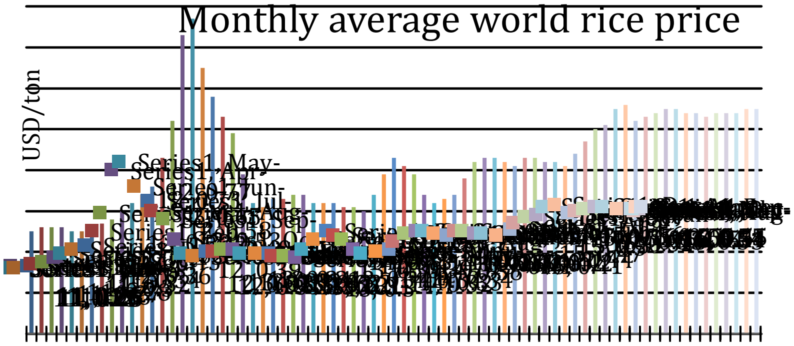
While rice makes up a majority of the world's staple food, it is also a vital resource in terms of food security, employment and export revenues. However, because it is prone to price and production fluctuations, variations can affect large parts of the world's population. The constant rise in consumption and price demands a higher productivity in order to avoid shortages. Also, while being a central determinant of food security (notably for countries with high demographic rates), trade plays an important role. It is forecasted that in the 2010-2015 period the Asia-Pacific region will be the largest consumer of rice.

Table 2 – Rice consumption prospects by region, 2010-2015 (VCPC, 2013)



As pictured in Table 3, important fluctuations in price can occur monthly, which can be caused by yield changes that, in turn, are influenced by meteorological, technical, infrastructural and trading causes. According to the International Rice Research Institute (IRRI, 2013), "both politics and monsoons can affect the rice market". Such diverse and mostly unpredictable fluctuations can have great effects on rice growers. Indeed, not only are rice farmers and processors highly dependent on the weather and the supply of energy to sustain their production, fluctuations in price greatly affect their capacity to reinvest funds for the next harvest. Since price mechanisms will ultimately determine the income of the farmers and other workers, reliability and stability of prices are the basis for continued production.

Table 3 - Monthly average world rice prices (Food Security, 2013)



Despite plans to create the Organization of Rice Exporting Countries (OREC) that would work on the same basis as the OPEC on price and production fixing, no substantial progress has been made. The various problems related to the changes in export and energy prices confer a high instability and add to the vulnerability of the rice sector. A sort of regulatory organization for rice producing countries would enable them to overcome financial and trade issues.

The implementation of RECP schemes would equip workers in the rice sector with a sustainable and lasting technology enabling them to be more independent from fluctuations in energy supply, and therefore be less affected by dramatic changes in market prices in the future. Also, with lasting problems in the financing of future crops, the integrated process offered by RECP would empower growers to invest on a sustainable basis. However, with more immediate and pressing concerns such as day-to-day income and trade, the implementation of RECP and its beneficiary effects might at first seem too ambitious and elusive. Up until recently, rice husk and other rice by-products were regularly dumped in rivers or burned. With around 20% of paddy weight being rice husk, the implications (and subsequent potential) of rice by-products are immense. In India, some rice husk power plants can light up villages and hamlets of up to 4,000 people (Santiaguel, 2013). An increasingly popular use of rice husk is its recycling in order to fabricate disposable chopsticks, therefore reducing the impact on forests.

While contributing to the food regime of large parts of the world's population, rice also employs great numbers of workers and makes up large parts of the agricultural sector in several countries. In 2012, worldwide total production of milled rice reached 476 million tons while consumption reached 466 million tons. In the same year, the total harvested area extended over 158 million ha reaching an average yield of 4.4 tons/ha, with both values growing year after year (USDA, 2013).

With a growing demand triggered by surges in population, rice will continue to be one of the most important edible commodities. Most importantly, all the processes leading to the domestic use of rice need to be identified and assessed since the production of rice is intimately linked to energy supply and consumption, transportation, industrial emission and governmental and multilateral policies.

Cambodia

In 2012, Cambodia reached a total production of more than 8.8m tons of rice, of which 83% came from rain-fed areas and 17% from irrigated land. In recent years, there has been a dramatic surge in paddy output, with the total figure doubling from 2000 to 2010 (4m tons to 8.2m tons; (Ministry of Agriculture, Forestry and Fisheries, 2011)). Plagued by a delicate political outlook, Cambodia finally reached rice self-sufficiency in 1985 and became a net exporter of rice and paddy in 1995 (SNV, 2012). Production of rice is projected to increase to more than 10.5m tons by 2020. More importantly, such figures are expected to be met without major addition to the actual area devoted to rice cultivation. In 2011, rice-cultivated areas were covering around 85% of the total cultivated land (2.8m ha) and employing around 2.9m people, making up for 60% of the total agricultural value (IRRI, 2012). Usually, three harvest periods occur yearly, with a yield attaining 3 tons per hectare. Despite this relatively low figure, it is rising dramatically with an average of a 5% increase every year. Such improvement is also necessary to counter the adverse effect of losses during processing, which range from 20% to 50% at all stages of the post-harvest chain, and as high as 30% during milling (ADB, 2012). At an average price of $390 per ton on the market, Cambodia can compete with neighboring countries (India, Vietnam) on the export market, but its efforts are greatly undermined by its neighbors' better energy infrastructures. Despite huge unregistered flows to and from neighboring countries, it is estimated that about 1.6m tons of paddy rice are informally traded over borders. Nonetheless, despite few fragrant and high quality rice imports, the balance in the trade of rice is firmly in favor of exports.

Vietnam

With a total production of 42.3m tons of paddy rice in 2011, Vietnam is the 5th largest producer in the world, accounting for 6.3% of the world's total paddy output (FAO, 2012). Also, since the 1989 reform of Doi Moi, which literally means "change and newness", Vietnam has gone from being a rice importer to a rice exporter, eventually becoming the world's second largest rice exporter since 1995. In Vietnam, rice is by far the most important agricultural product with paddy (7.6m ha) representing 53% of the total cultivated area, of which 97% is irrigated (USDA, 2013). As the main agricultural product in Vietnam, in 2011 rice accounted for as much as 39% of the total agricultural production value (FAO, 2012). Actual employment in the rice sector is difficult to assess since it is estimated that about 80% of the population is to some extent involved in rice production, of which 50% make a surplus out of its trade (UNEP). With three harvests per year and a yield of around 5.7 tons per ha in 2012, Vietnam also manages to minimize its post-harvest losses at around 12% in 2012, making it a relatively good-quality rice (USDA, 2013). In 2012, Vietnam's rice exports of 7.4m tons accounted for nearly 20% of the world's total exports, at an average price of $490/t (USDA, 2013). According to the OECD and the FAO, Vietnam's rice production is expected to grow over the years, driven notably by better yield results.

Colombia

The rice milling industry in Colombia is one of the most dynamic industrial activities when compared with the total of National Industry. It has low production costs, mainly achieved through economies of scale, and efficient technologies. In Colombia, the main activities related to rice industry is the purchase of green paddy, the sale of with rice and the intermediate processing. There are few competitors in the sector, especially in packaging.

In 2011, Colombia produced a total of 1,857,154 tons of rice, making it the third-largest rice producer in America, behind Brazil and the United States. Overall, 65% was produced via an irrigation system and 35% via a rain-fed system (FAO, 2012). On a general trend, rice production has been declining in recent years and the ratio of irrigated production is declining in favor of rain-fed production. In the same year, around 12% of total cultivated land (equivalent to 430,089 ha) is dedicated to rice production, accounting for about 5% of the total value of agricultural production (FAO, 2012). As for employment, 2010 numbers show that rice industry makes up for 3% of the total agricultural employment[4] and 6% of total employment, respectively. With two crops per year, Colombia has an average yield of 5 tons per hectare. Colombian rice production is experiencing processing losses of up to 32% but the local production is granted a high level of protection[5], leading to rice imports to be virtually non-existent. On the market, Colombian rice has an average price of $487/t[6] but is generally not exported, because the national demand is usually higher than the national production.

Peru

In 2011, Peru's total rice output reached around 2.6m tons, with rice fields covering around 12% of the total cultivated land (FAO, 2012). Accounting in 2011 for nearly 8% of Peru's total agricultural production value, rice was produced mainly (93%) via an irrigation method. Over the last ten years, Peru's rice production has floated between 1.8m tons in 2004 and 2.9m tons in 2009. Official bodies in Peru estimate that rice employed 161,300 permanent workers 2012 (MINAG, 2013) and is generally harvested twice a year. Despite high yield results (an average of 7 tons per ha) and low rates of losses (less than 12%), imports are still needed to provide for Peru's national consumption (USDA, 2013). Therefore, all the rice produced and processed in Peru is consumed nationally, which makes it a net importer state. This deficit in trade coupled with high productivity needs to be put in balance with other factors. Indeed, only 16.7% of Peru's territory is arable, a low figure mainly explained by its mountainous topography (Trading Economics, 2013).

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[4] 66,273 direct and 257,920 indirect employees

[5] Protection taxe of 80% ad-valorem on paddy, brown and milled rice imports

[6] COP900,000/t, it reached COP1,138,000/t in 2012

2.2 Stakeholder overview

2.2.1 Rice growers, technology and energy supply, biowaste use

Cambodia

Usually, because of a lack of infrastructure, rice production and processing are not integrated in Cambodia. Rice farmers usually sell their wet rice to Vietnamese and Thai buyers, missing opportunities for value-addition. In 2010, it was reported that Cambodia had around 24,000 mills (including homemade and custom mills), while it was estimated that small-size units accounted for 96% of the total number of rice millers. Cambodia is mostly equipped with old technologies with the majority of mills using second-hand equipment from Vietnam and the People's Republic of China, which generate higher levels of broken rice. With relatively low reliability of energy supply, limited access to energy sources and very few government supported energy supply, the rice sector in Cambodia highly depends on expensive imported fuel products. Around 18.8 liters of diesel are necessary to mill one ton of rice, which is the equivalent of about 54kWh per ton. Mainly because the milling phase is the most energy demanding phase, it accounts for 65% of the processing costs Despite some secondary use of by-products (husk, straw) for industrial purposes, there is still a lack of technology and know-how in the transformation processes. 2.37m tons of rice husk and 2.9m tons of rice straw are produced per year, out of which only about 10% is used as biomass fuel. Finally, there is insufficient data and only a few systematic studies on the sector, making biomass valorization assessment difficult for project developers.

Vietnam

The lack of storage facilities, which prevents producers from taking advantage of market fluctuations, is in favor of resellers and trade businesses, therefore diminishing the growers' influence and interests on the international market. With the total surpassing 100,000 mills units in Vietnam, a vast majority of them are homemade units with a milling capacity below 3 tons of paddy per hour. Two state-run companies dominate the large-scale rice processing sector: the Viet Nam Northern Food Corporation and the Viet Nam Southern Food Corporation, who enjoy favorable tax regimes, better access to export markets and better access to capital from state banks. Vietnam enjoys relatively good equipment, enabling the industry to minimize its broken rice ratio and obtain high yield results. Vietnam's low-priced and government-subsidized electricity enables most rice mills to run on grid electricity. On the downside however, soaring demand has seen electricity prices increase by 15%. As a result of this, Vietnam's industrial sector is looking to develop its own power supplies. To produce a ton of mechanically dried polished white rice, between 70 and 110kWh are necessary. However, for a ton of sun dried non-polished white rice, about 45kWh is required. With around 8m tons of husk generated annually from rice production, biomass valorization is a central issue for Vietnam. At the moment, waste processing is used for mushroom cultivation and as organic fertilizer (rice straw), alternative fuel, winter fodder for cattle or rice wine (rice husk). However, it is reported that in 2012, rice millers discharged nearly 4m tons of rice husk in the Mekong Delta, raising concerns on the sustainability of the rice sector.

Colombia

Most of Colombia's milling is done by large enterprises that are responsible for processing the paddy rice bought from farmers. A rather unique aspect of this scheme is the obligation of these milling enterprises to get involved in the financing of farmers, the commercialization of agricultural inputs (e.g. fertilizers and chemicals), the storage of dry grains and the development of new rice by-products (ANDI - Induarroz, 2013). Colombian rice mills can be classified into 4 groups according to their level of technology and processing capacity. The first group is characterized by innovative enterprises relying on foreign technology processing more than 50,000 tons of paddy rice per year. The second group is made up of companies using national technology to process generally around 20,000 tons per year. The third group usually relies on old technology continuously processing between 3,000 to 10,000 tons per year. Finally, the fourth group is made up of small and homemade mills producing less than 3,000 tons per year (Espinal, 2005). The rice industry works much like an oligopolistic organization with 7 main companies concentrated around 80% of the milled rice supply of the country (Espinal, 2005). The majority of milling installations have advanced technological features, therefore allowing high rates of production development. Hydropower (64 – 67%), gas (27%) and coal (5%) are the main sources of energy. With the country relying on hydropower for the bulk of its electricity, it is relatively affordable, without being subsidized by the government. On the regulation side, up to a consumption of 0.5 MW, the government establishes the tariff structure. Above that, consumers with higher power demands (such as rice millers) can freely negotiate with suppliers. Of the 0.4m tons of waste generated by the production of rice, around 15% is used as alternative fuel. On top of that, husk is also used for landfills, soil conditioning, “truck beds” for animal transport and briquettes production (Aguilar, 2009).

Peru

Peru has around 600 mills, of which 98% are industrial and relatively large. With nearly all of the mills privately owned and virtually no exports, favorable tax regimes apply to producers. During the processing phase, about 98% of the process is conducted by large industrial mills, using relatively modern equipment. However, on the producing side, the most common size of farms is between 5.01 and 10 Ha (see Table 4). Rice farmers are therefore quite scattered and RECP schemes need to take into account the localization of by-products and the possibility of on-site building. According to the International Energy Agency (IEA) 92% of Peru’s energy supply is obtained via hydro- and gas-power (58% and 34%, respectively) with virtually no exports and imports. Despite a lack of energy subsidies from the government, energy is normally less than $0.1 per kWh. As for access to electricity, national coverage in 2012 was estimated at 87.2% (MINEM, 2013). To obtain a ton of dried rice, about 55kWh is needed. Waste processing depends on the region, and includes animal food, detergents or poultry bedding. Officially, open burning of rice husk is illegal, leading some producers to simply transport it and compact it. At the moment, only about 5% of rice husk is used as fuel, notably in brick manufacturing (Assureira E., 2002), the rest is either compacted and stored, or simply left to decompose. But with a relatively low amount of waste (0.7m tons in 2011) and an already existing utilization of this waste, incentives to improve their utilization are low. Therefore, with low amounts of by-products and a relatively efficient industry, the improvement of energetic biomass is relatively more difficult to implement.

2.2.2 Rice market actors

Cambodia

The large exporters that have integrated rice milling in their pre-trade activities should be considered a priority for RECP investments as they might have the most incentive to reduce the cost of processing. There are two major nationwide associations in the rice processing sector; the Rice Millers Association, organized by Green Trade Company under the supervision of the Ministry of Commerce, and the Federation of Cambodian Rice Millers Association, set up by rice millers in the Battam Bang province. Despite the existence of such associations, it is generally noted than provincial organizations are more functional and efficient. Beside the informal exports of paddy to neighboring countries, the state-owned Green Trade Company manages most of the exports. The organization oversees 5 companies that handle between 31,000m and 10,000m tons, 8 companies that handle between 10,000m and 4,000m tons, and 17 companies that handle between 4,000m and 1,000m tons (SOURCE). Under the "Everything But Arms" scheme, Cambodia can benefit from duty-free and quota-free exports to EU countries, which positively influences its exports.

Vietnam

As mentioned earlier, the lack of storage spaces and infrastructure is in favor of resellers and exporters who can therefore solely impact the gains made form exports. Also, because they enjoy better access to export markets and capital, the Viet Nam Northern Food Corporation and the Viet Nam Southern Food Corporation control most of Vietnam's exports. This is notably due to the No. 109/2010/ND-CP decree and No. 44/2010/TT-BCT circular limiting the participation of private companies in the rice export market by requiring large infrastructures from rice processing companies, which severely limits their access to the exports market. To regroup the variety of actors participating in the export market, the Thai Rice Exporters Association acts as a coordinating inter-professional organization.

Colombia

Colombia is supposed to be self-sufficient in its rice supply, even though rice imports from Ecuador and Venezuela have been recorded (USDA Foreign Agricultural Service, 2009). Three mains entities compose the organizational stakeholders: the Fedearroz (National Rice Growers Federation), the Acosemillas (Colombian Association of Seeds), and the Induarroz/Moliarroz (Rice Mills Industry Federation). The main national rice association and the one with the largest number of members, the Fedearroz, is aimed at defending the rice farmers' rights and enhancing equipment quality. The main goal is therefore to increase the economic efficiency and competitiveness of the rice sector. However, limited access to credit, no favorable tax regime and virtually no exports for the rice sector, contribute to a difficult situation for the growers and the millers. Industrial rice mills are affiliated with the Federation of Industry of Rice (Induarroz), created to ensure the sustainability of rice activity and competitiveness of all the agents involved in the chain. Induarroz is actively involved in the rice sector by consolidating information related to the national inventory of dry paddy rice, white rice production, apparent consumption of rice and industry capacity. The information collected is used to make decisions for the industry, such as the reference pricing of green paddy.

Peru

Two nationwide organizations are active in the rice sector: the Asociacion Peruana de Molineros de Arroz (APEMA) and Asociacion de Productores de Arroz (APEAR), but it does not look like they have a major influence on the whole of the industry. Indeed, their low financing does not allow them to compete with government programs and institutions such as the Ministry of Agriculture (MINAG), the National Institute of Agrarian Innovation (INIA), and the Gobiernos Regionales (GORE).

The World Economic Forum's Global Competitiveness Index (World Economic Forum, 2012) establishes a ranking of the competitiveness of countries in global trade and highlights the main factors that hinder business.

WEF GCI 2012/13	**Cambodia**	**Vietnam**	**Colombia**	**Peru**
Rank (in brackets: 2011/12 rank)	85th (97th)	75th (65th)	69th (68th)	61st (67th)
Main factors making business difficult	▪ Corruption ▪ Inadequately educated workforce ▪ Inefficient government bureaucracy ▪ Difficult access to financing	▪ Difficult access to financing ▪ Inflation ▪ Inadequate supply of energy	▪ Corruption ▪ Inefficient government bureaucracy ▪ Inadequate supply of infrastructure	▪ Inefficient government bureaucracy ▪ Corruption ▪ Restrictive labor regulation ▪ Inadequate supply of infrastructure

2.3 Technical and Financial support to RECP

Cambodia

On the financing side, most millers depend on their own savings coupled with bank loans. However, as mentioned when discussing the WEF GCI, Cambodia's issues with inefficient government bureaucracy and difficult access to financing make it harder to obtain transparent information on financial mechanisms. Nationally, priorities of the government revolve around an intensification of production and recent policies have set a target of 1m tons of processed rice exports by 2015. However, with limited means of cooperation between various ministries and a rather timid and still forming financial sector, obstacles are abundant. The lack of a legal framework to support financial and production enhancement of the rice sector does not allow the sector to work with clear standards, therefore hindering their capacity to enhance exports and sell at higher prices. Several cooperation programs and schemes are active in Cambodia: the French Development Agency, the Swedish International Cooperation Agency, the SNV Netherlands Development Organization (SNV), and the Clean Development Mechanism (CDM). They all have among their objectives to enhance cooperation towards innovative cleaner production support schemes, studies on investment by rice millers, support the rice value chain, modernize the methods of funding, develop the gasification technology and enhance the capacity of stakeholders. For example, the SNV-initiated "Waste to Energy for the Rice Milling Sector" project envisages reducing the utilization of diesel by 4.5m liters – or the equivalent of 43,000t of CO2 – per year (SNV). In addition to that, the project plans to reach an income of $137/ton of milled rice, of which $123 will go to the workers and $14 to taxes.

Vietnam

Access to financing greatly depends on the size of the mill. While both custom and commercial mills mostly depend on their own financing (69.4% and 85.1%, respectively), custom mills also depend on financing from relatives and private companies (JICA, 2010). The cooperation between the SECO, Switch Asia and the CDM scheme intends to help enterprises access financial sources in order to implement clean technologies, support the rice value chain, enhance the energetic valorization of rice by-products and implement solar energy for rice drying. For now, government policies focus on infrastructures and technologies such as irrigation, hybrid species that could withstand drought and flooding, storage facilities, rural roads and electricity. The main aim of these different developments is an increased yield motivated by the prospect of reducing the cultivated area but still maintaining high levels of production. In 2004 the government issued a strategic orientation towards the implementation of Agenda 21 in Vietnam, in which RECP technologies are referred to in 7 out of 18 priority areas. According to this strategy, newly constructed and recently invested establishments (farms, mills, storage facilities) would have to invest in clean technology and environmentally friendly production that would discharge less waste.

Colombia

Because the Colombian rice market is highly protected, farmers and millers can rely on relatively stable prices to fund their next seasons. According to the University of Arkansas, Colombian rice prices are among the highest in the world. They are twice as high as Brazil's and nearly three times as high as Argentina's and Uruguay's. Also, it appears that these high prices directly profit consumers (University of Arkansas System, 2012). Therefore, most farmers and millers rely on government funds to financially support their work.

The Colombian rice industry has several roles within the chain: rice producers and stores financing, collecting, conditioning, storing, processing, but also product marketing, development and sale.

Peru

It is reported that loans for rice processing companies are relatively easy to access, which is not the case for farmers who rely mainly on processing companies for their financing. According to (APEAR, 2010), to finance their production, farmers rely first on millers (32.4%), followed by exporters (28.4%) and government funds (20.3%). The intertwining technologies and financial aid provided by organizations such as USAID, Fondo de las Américas (FONDAM) and Ökozentrum contribute to a variety of new developments. Locally, the SECO's Linéa de Credito Ambiental has successfully helped 4 out of 5 mills in the country and nearly all rice-processing plants have replaced diesel with electricity. Still, according to (APEAR, 2010), the main problems affecting the production of rice are low prices (87.1%), financing (74.3%), lack of technologies (68.6%), pests and diseases (64.3%) and quality of seeds (57.1%) (See Table 5).

2.4 Institutional and policy framework assessment

Cambodia

A few regulatory laws on the environment and energy need to be mentioned, with notably the Environmental Protection and Natural Resource Management Law of 1996 crucial in the setting up of the Environmental Management Plans (EMP) and the Law on Pesticide and Fertilizer Management prohibiting the use of Persistent Organic Pollutant (POPs), crucial in the potential application of RECP. Indeed, a better regulation of the use of by-products and waste could set important legal rules and frameworks for a steady implementation of environment-driven technologies. The priority for investment in the rice sector is mainly concentrated on increasing the producing capacity, relegating the prospects of cleaner production to a secondary priority. However, both achievements are not incompatible. For most of the small milling units, RECP seems to be difficult to attain since other issues and concerns are considered more vital such as the overall Rural Electrification (RE) program. But, concerns over the supply of energy could trigger an incentive to invest in RECP technologies in order to reuse the waste and residues generated by the production of rice for energy. Also, the valorization of by-products for cement is an attractive possibility.

Vietnam

Efforts have been made in the energy efficiency sector with notably the 2003 Governmental Decree on Efficient Utilization of Energy and Energy Conservation, the 2007 Chemical Law relating to resource efficiency and safety, the 2010 Law on Energy Efficiency and Conservation (EE&C). Moreover, the 2009 Strategy on Cleaner Industrial Production to 2020 brings new developments in all industrial sectors with the government setting two main goals. Firstly, by 2015, 50% of the industry should become aware of the benefits of industrial production while 20% of the industry should adopt cleaner production in order to save 5-8% of energy use. Secondly, by 2020, both these goals should reach 90% and 50%, respectively. Finally, despite several plans to implement clean technology, Vietnam's priority is to enhance productivity without particular regard to the treatment of secondary by-products, therefore reducing the potential impact and importance of RECP guidelines and technologies. However, just like in the Cambodian example, a steady implementation of RECP technologies would enable producers to rely less on the national energy supply and therefore enable them to independently enhance their production. Indeed, with energy prices steadily increasing, the valorization of by-products for industrial furnaces is an appealing possibility.

Colombia

In 2009, due to an increase in the cultivated area as well as in total production, oversupply and low prices plagued the Colombian rice sector. In order to cope with such problems, the government set a minimum price for growers and assigned a budget of $17.5m. With only a few international cooperation schemes in place, the government's priority lies in the strengthening of the agricultural milieu, and not necessarily in the enhancement of RECP schemes in the rice sector. However, several programs already focus on the reuse of rice processing by-products, notably in the construction and fertilizers sectors. With relatively high levels of production, Colombia has a good potential for a reuse of by-products as an energy source. Finally, just like in the other examples, the main barriers for implementation of RECP projects are the extensive spatial distribution of wastes and their uneven production throughout the year. Such problems require on-site valorization (implementing the projects next to the mills) that would also lower transportation costs and time.

Peru

National programs include the Programa de Investigacion de Arroz (PIA-PERU) of the Instituto Nacional de Investigacion y Extension Agraria (INIA), the AGROBANCO, the AGRORURAL, the AGROIDEAS and the Programa Subsectorial de Irrigaciones. On the legal framework side, several improvements are taking place. The Ley General del Ambianto (Ley no. 28611) establishes guidelines and policies regarding the use of sustainable resources and promotes their conservation, and the Ley General de Residuos Solidos (Ley no. 27314) provides eco-efficient measures on the reuse and recycling of solid waste. However, with low electricity prices, there is no acute motivation to benefit from lower production prices. Also, just like in Colombia, pedological and topological features incur that production is mostly done in remote areas, therefore creating physical barriers to distant technologies. But overall, with a relatively low figure of production, a quite developed infrastructure and several institutional and legal advances making room for technological advances, Peru has strong incentives to implement RECP schemes that would set an example.

Rice production	**Cambodia**	**Vietnam**	**Peru**	**Colombia**
Type of production	83% rainfed 17% irrigated	97% irrigated	65% irrigated 35% rainfed	93% irrigated
Share in cultivated area	85-90%	53%	12%	12%
Share in total agricultural production value	63%	39%	5%	8%
Employment	2.9m	N/A	66,000 direct 260,000 indirect	161,300
Total production (m tons, 2011, FAO).	8.8	42.3	2.6	1.8
Harvest	3	3	2	2
Yield (tons per ha, 2010)	3	5.3	7	5
Waste qty. (m tons per year)	5.27	8 (husk only)	0.7	0.4
Losses	35.6	12	11.7	32
Competitiveness index (WEF)	85th	75th	61st	69th
Energy necessary for 1t of finished rice	≈ 54kWh	70-110kWh	55kWh	N/A

Part 3. Cleaner Production Potentials

3.1 Selected rice processing companies in the different countries

3.1.1 Specific features of selected companies

Visited processing companies in Peru are small sized and characterized by low motivation for RECP, and therefore have less available data and no RECP dedicated representative. As the representativeness is high, companies are nevertheless prone to replicable RECP potentials.

The situation is similar for Cambodia, but the size of companies is slightly bigger and they often partly export their production, especially to Vietnam. The motivation for RECP is rather low, thus generating difficulties for accessing reliable data.

Colombia is characterized by significantly larger mills, with relatively higher financial capacities allowing for an increased company motivation, with staff dedicated to RECP projects and available data. As a result, RECP-related solutions have already been carried out, reducing the potential to implement low-hanging fruits.

The identified mills in Vietnam are characterized by geographic dispersion, which does not facilitate CP assessments in general. However, as the initial sample of companies includes a significant part of exporting companies, the situation with respect to organization, data availability, motivation, and representativeness is quite good. The overall rating shows that the RECP potential is not fully exploited. Indeed, in almost all Vietnamese companies, resource and waste management, as well as processing activities, can be improved to reduce resource and energy intensity.

In all countries, rice mills are located in remote areas and are difficult to access, posing logistic problems when by-products need to be transported on long distances for valorization.

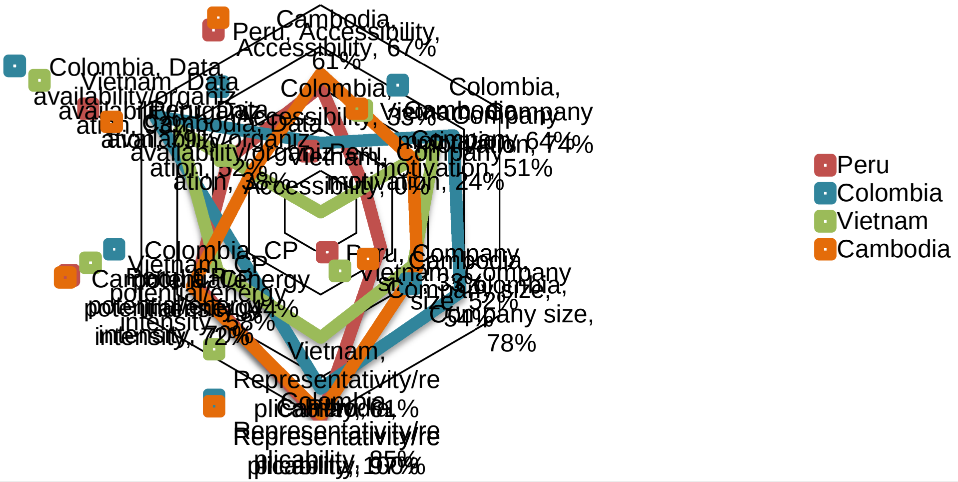

Figure 26 - Company representativeness with regards to selection criteria

3.1.2 Typical rice production flow chart

The typical process flowchart varies significantly across the 4 countries. Nevertheless, a generic process flow diagram for resource consumption and waste production has been sketched in the following figure. Row thickness is only an indication of the flow importance and cannot be considered as a systematically observed rule.

The graph below illustrates the most common process flow chart identified across the **wet paddy millers** that were selected. The system boundaries presented in this chart represent the processes generally observed in Colombia and Peru, where millers are also landowners and control a large part of the rice value chain. Colombian millers are also those who have implemented the most paddy drying with on-site husk fed dryers.

Only one Cambodian rice miller is currently running a dual fuel gasification system producing electricity partly from rice husks and partly from diesel. This allows him to significantly reduce diesel consumption and processing costs.

Some Cambodian and Peruvian millers are practicing a sun-based drying process, or a combination of sun and mechanical drying process, which affects rice husks reuse. It can also affect white rice quality and losses.

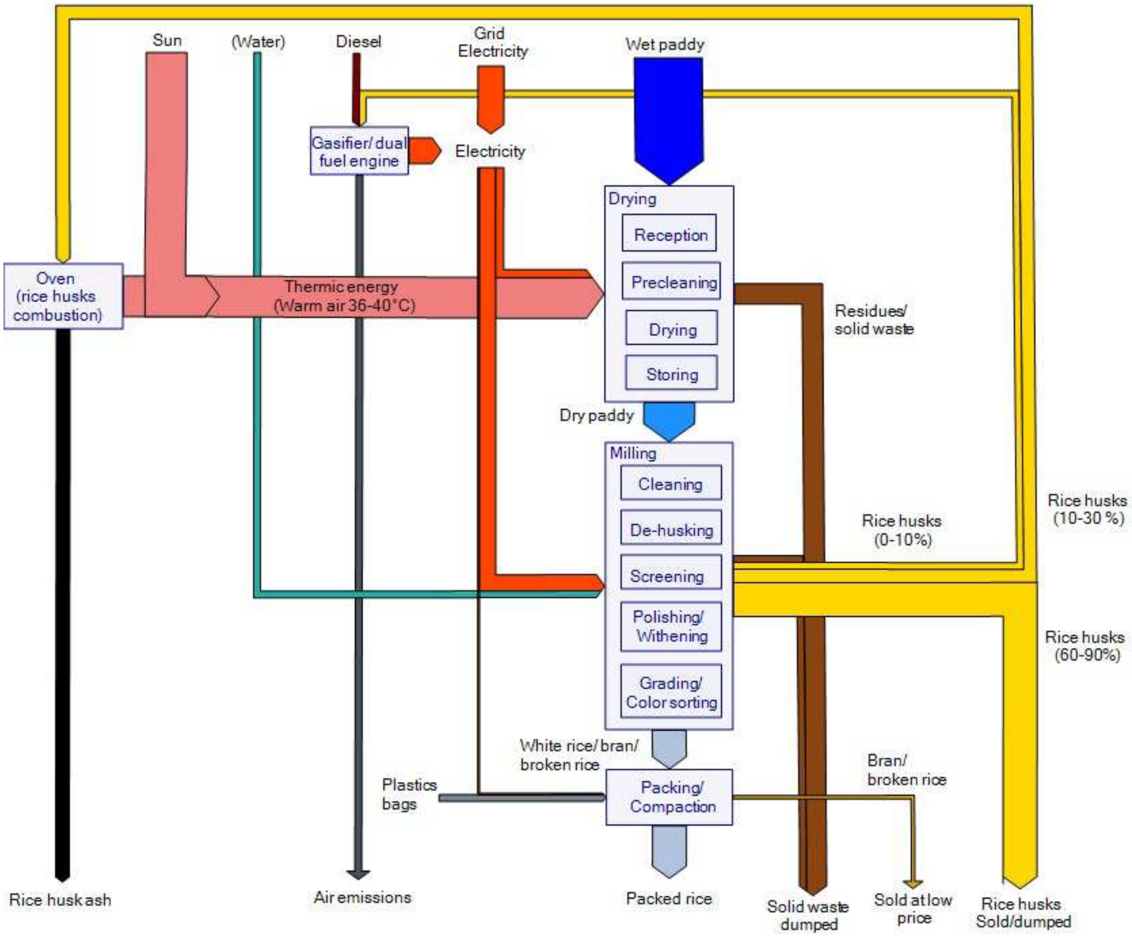

Figure 27 - Generic process flow-chart identified across the selected rice mills

The rice supply chain in Vietnam is very fragmented, with different actors carrying out the processes that take place in Colombian, Peruvian and Cambodian mills. The audited Vietnamese mills process **brown rice**, which is the intermediate product after the dehusking and drying processes. This specificity makes the comparison of their performance with those of mills from the other countries difficult.[7]

The potential for RECP solutions in Vietnamese mills is therefore very different from the mills in the other three countries. Because the de-husking and drying processes take place in smaller units up-stream in the value chain, the possibility of reusing husks for energy production is reduced. Nevertheless, they usually process a large quantity of paddy and are big electricity consumers, with significant room for improvements in the electric efficiency of their machinery.

3.1.3 RECP potentials identified by millers

According to the audited millers, the main potential for RECP solutions can be summarized as follows:

1. E**lectrical and thermal energy** consumption deserves a particular attention, especially because of significant consumptions in the drying, milling and sorting processes.
2. **Raw material losses** caused by inappropriate handling or processing are also one the main concerns.
3. **Waste – especially husks – reuse** as source of heat for the drying process is already being carried out in some units and has an interesting scaling-up potential.

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[7] Please refer to Annex B for a detailed Vietnamese process flow chart.

3.2 Resource consumption indicators

3.2.1 Fossil fuel, power, and husk reuse indicators

Colombia and Cambodia have the highest energy demand per unit of white rice produced, no matter which type of energy is concerned. Although Cambodian companies have a high grid electricity cost that constitutes an evident energy supply limitation, the consumption can be compared to Colombian companies. Another important observation concerns the variety of energy used by Cambodian mills, where high electricity costs from the grid encourage for the implementation of gasification of husks and the use of diesel generators, which are not widely used in other countries. Nonetheless, the reuse of rice husks is still under-exploited as large quantities are still disposed of, even in Cambodia.

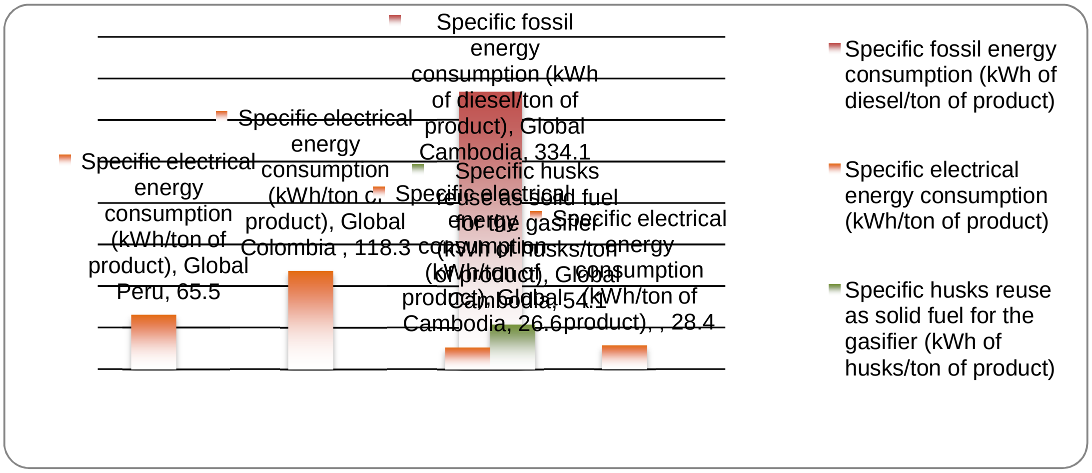

Figure 28 - Aggregated indicators for fossil and power consumptions, and husks reuse

3.2.2 Paddy consumption and by-product production indicators

Specific raw material consumption as well as solid waste consumption are comparable across countries. Surprisingly, the audited Peruvian and Colombian companies appear to have the highest rate of loss during the processing, a result in contradiction with the general country appreciation as described in Part II of this report. This may be explained by the fact that there are less harvests in the Latin American countries, resulting in longer storage periods for the dry paddy before it can be processed, thus resulting in a higher risk of losses.

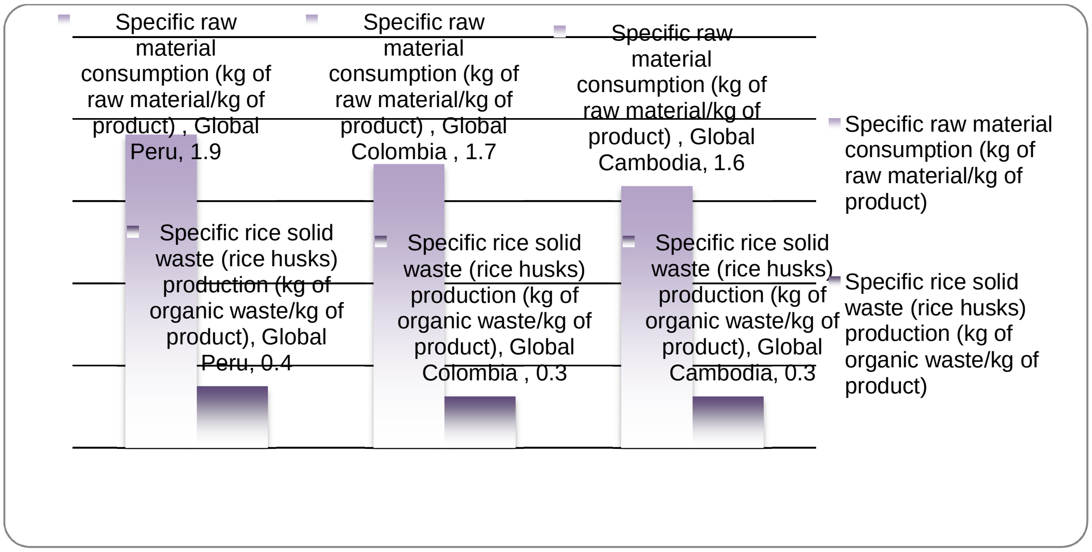

Figure 29 - Aggregated indicators for raw material consumption and rice solid waste (Peru, Colombia, Cambodia)

Because of the fragmented nature of the vietnamese rice processing sector, the results for the audited companies are presented in a separate figure below. The four audited companies already receive dehusked rice (brown rice), which significantly reduces the use of resources compared to the other rice millers in different countries.

Consecutive losses occur during polishing steps and do not include husks, but bran and broken rice.

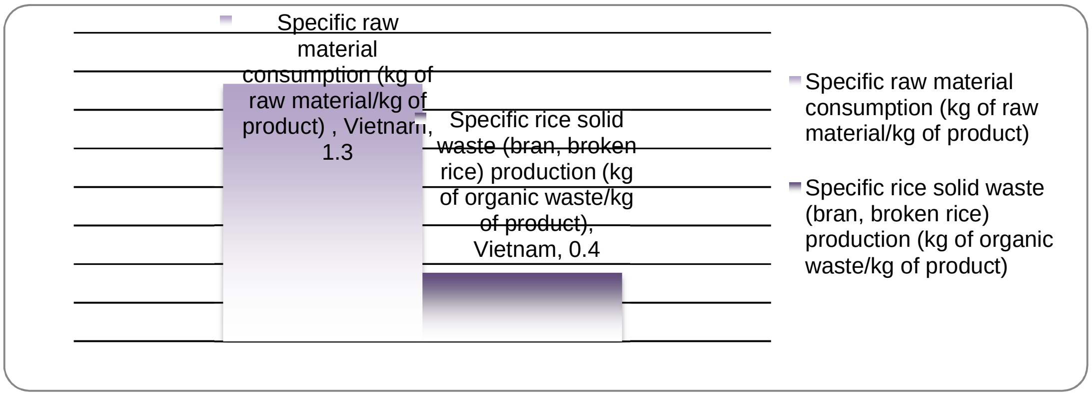

Figure 30 - Aggregated indicators for raw material consumption and rice solid waste (Vietnam)

3.2.3 Thermic consumption and husk reuse indicators

Rice husk is the main source of thermal energy for drying the paddy, as shown in the graph below. The difference in thermic energy consumption between the countries is mainly explained by the importance open sun drying takes.

In Peru for instance, half of the audited companies do not need additional heat for the drying process

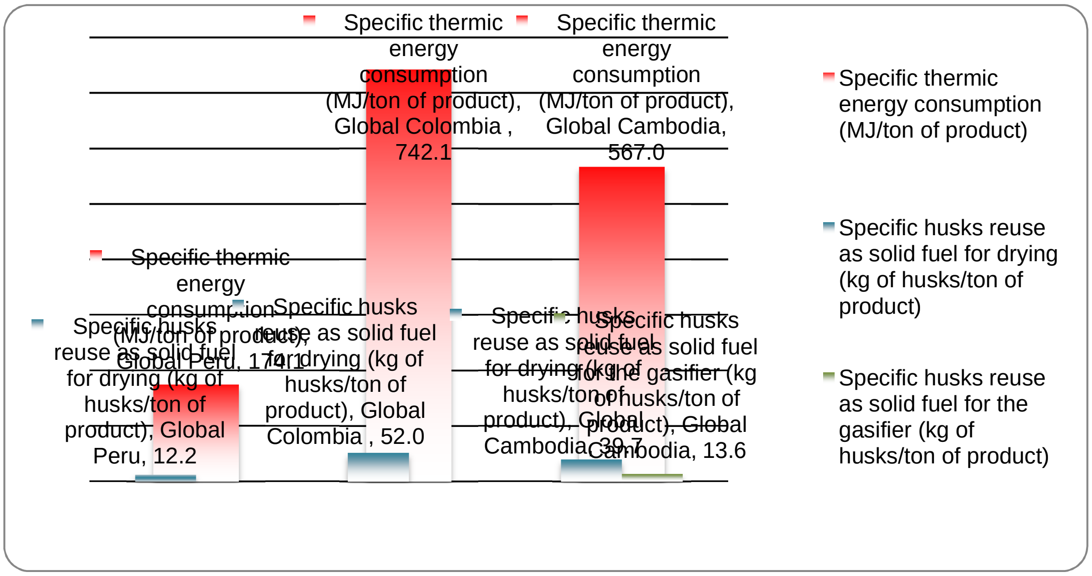

Figure 31 - Aggregated indicators for thermic consumption and husks reuse

It is difficult to conclude what system performs best from an RECP perspective. On the one hand, sun drying doesn't allow for the valorization of rice husks, which are disposed of in dumpsites and burned in the open to reduce volumes. On the other hand, the wide use of rice husk for drying produces significant amounts of ash with a high silica content that is currently not valorized.

In addition, rice quality considerations need to be equally taken into account for a faire comparison.

3.2.4 Specific CO2 emissions indicator

Greenhouse gas emissions are calculated based on the diesel and power consumptions at the rice mills.

The CO_2 emission factors for grid electricity of each country are presented in the following table, and differ significantly from a country to another. Such differences in emission factors heavily burden carbon emissions and can explain why Colombia's emissions are lower than Peru's for a higher specific electrical consumption.

Carbon emission factors of grid electricity	kg of CO2/kWh
Colombia	0.28
Peru	0.547
Vietnam	0.576
Cambodia	1.205

The grid power consumption differs significantly between Peru and Colombia, and probably results from different process designs, Colombian rice mills have more automated processing lines powered by electricity.

In Cambodia, poor access to grid electricity induces a wide use of diesel powered back-up generators, thus heavily impacting CO2 emissions.

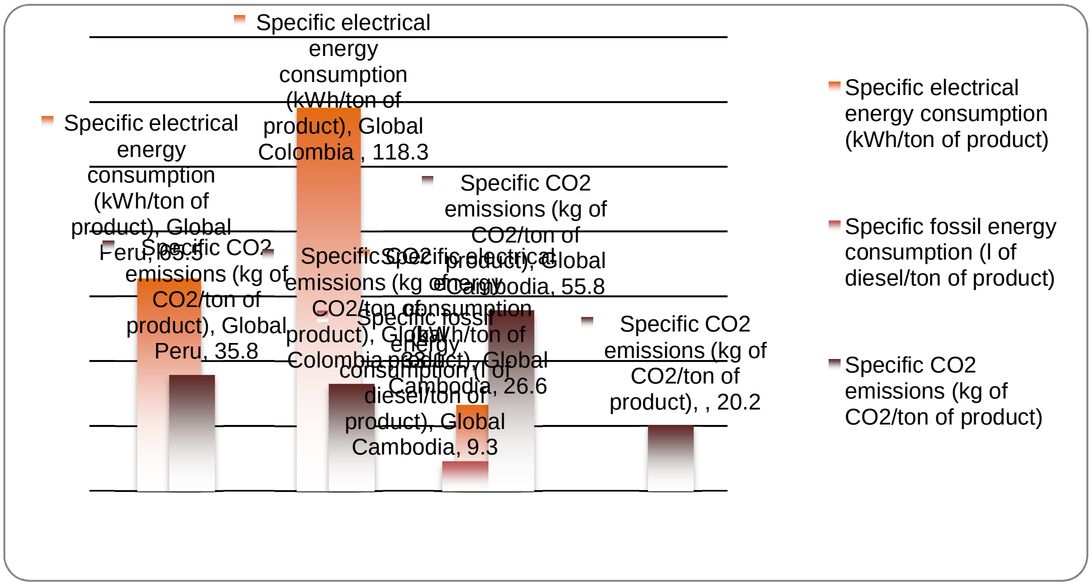

Figure 32 - Aggregated indicators for power and fossil fuel consumptions, and CO_2 emissions (Peru, Colombia, Cambodia)

In Vietnam, although brown rice is usually already dried before being supplied to the mills, residual moisture requires an additional drying process that is usually fired by burning coal. Coal consumption remains relatively low but significantly varies depending on the moisture content of the brown rice.

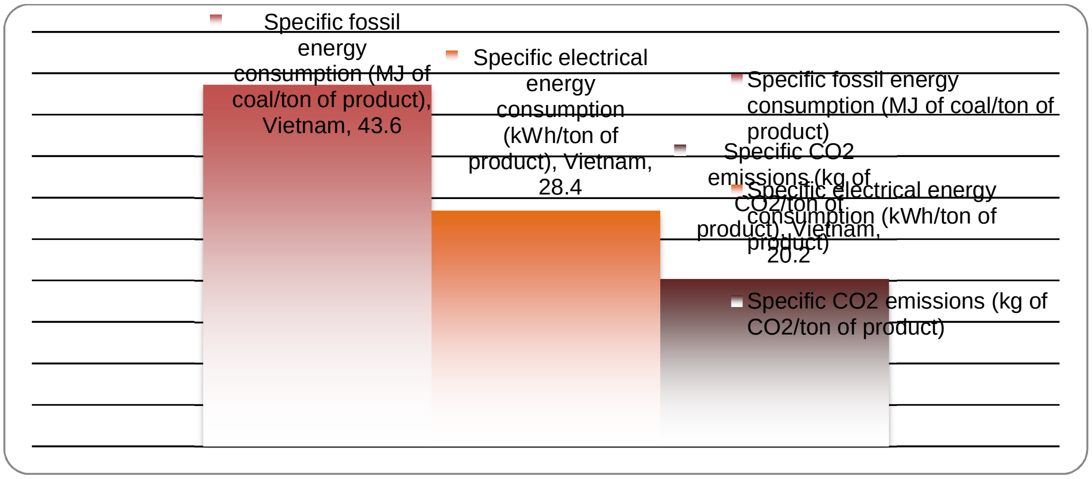

Figure 33 - Aggregated indicators for power and fossil fuel consumptions, and CO_2 emissions (Vietnam)

3.3 Identified CP potentials and opportunities

3.3.1 CP measures classification

CP options may fall into different categories according to the CP-EE manual (UNEP, 2004).

The figure below presents the number of different measures that were recommended in each country.

In general, recommended measures generally belong to the following categories:

- Good housekeeping
- Recovery of useful by-products, material and energy
- Equipment modification

Other categories are of interest because of their occurrence: the efficient use of energy and process optimization.

The distribution of recommended CP measures across the different categories is subject to the interpretation of the terminology by the local stakeholders, and should not be considered rigorously.

	Peru	Colombia	Cambodia	Vietnam
Housekeeping	**27**	**15**	**18**	**14**
Management and personnel practices	7	0	3	0
Process optimization	3	5	**10**	0
Efficient use of energy	8	0	5	6
Raw material substitution	0	0	6	4
Recovery of useful by-products, materials and energy	7	5	**10**	4
On-site recycling and reuse	0	0	0	0
Equipment modification	**15**	**10**	7	**9**
New technology	0	0	2	0

Nevertheless, several conclusions can be drawn from the figure above:

1. In all countries, millers show a specific interest regarding low-cost options that can provide moderate to high benefits. In other terms, housekeeping options oriented towards energy savings and product quality improvement are often mentioned.
2. Rice husk is widely under-valorized and disposed of in dumpsites. The valorization of rice husks presents by far the largest potential in terms of low-carbon production, but requires access to relevant technology and high investment costs.
3. Energy costs, especially electricity, is a main concern for most of the mills. Monitoring power consumption is the first step towards significant savings.

4. Inefficient equipment – mainly motors - in Peru and Colombia present an interesting potential in electricity savings.

The separate annex document (annex D) presents a detailed description of CP options.

3.3.2 Description of the proposed CP measures

I. <u>Housekeeping</u>

The importance of equipment maintenance and cleaning operations is generally under-estimated across the audited companies. Good housekeeping measures aim at preventing equipment failure, product quality deterioration and improve overall process efficiency.

For instance, a proper maintenance of the compressed air network - a significant power consumer - allows avoiding especially leakage and over-consumption of electricity.

Another housekeeping measure often lacking is the monitoring of resource consumption, production and by-products outputs. Simple baseline data on power or water consumption, and waste or by-product generation is too often not available.

II. <u>Management and personnel practices</u>

Often improvements in terms of resource consumption and product quality narrowly depend on capacity-building and awareness-raising programs for employees. Most of the successfully implemented CP measures are closely correlated to the correct appropriation of company staff.

III. <u>Process optimization</u>

The main measures allowing for process optimization are energy, equipment and product quality management. For instance, compressed air is often produced in excess and does not match the real demand for operating pressure.

The design of the processes also requires proper engineering in order to avoid voltage losses between machines or clogging air filters on motors and compressors with dust. Simple optimized processes often allow picking low hanging fruits and generate significant energy and financial savings.

Even if the sun-based drying process is interesting in terms of energy consumption and cost, it is not easy to carry out properly, especially because it often induces moisture variability and therefore quality problems. In Peru, sun-drying conditions can be improved as a first step, and then if the investment capacity is sufficient it is recommended to use industrial driers running on rice husks in order to avoid product quality issues.

IV. <u>Efficient use of energy</u>

The first step to energy efficiency depends on a good housekeeping measure, that is to monitor consumption and obtain reliable data allowing for instance to locate unexplained over-consumption or to define priorities in terms of equipment or process improvements.

Inefficient energy consumption is also sometimes generated by poor process design affecting the working voltage or conductor area.

V. *Raw material substitution*

Vietnamese and Cambodian millers usually adapt the process flow sequences depending on the paddy quality and especially the moisture content. Raw material selection could then help to ease the transformation. Indeed, moisture variability means more complexity in the processing steps. Nevertheless, wet paddy implies increasing costs for drying, whereas field dried paddy has usually poor quality. The trend is in favor of improving product quality, which means increasing demand in thermal energy.

VI. *Recovery of useful by-products, materials and energy*

The largest share of rice husk is generally dumped in backyards. The potential of these by-products is largely under-exploited. Despite an increased use for drying the paddy, it usually constitutes a small fraction of the available husks and other reuse opportunities should be assessed to turn these wasted husks into a useful resource.

A variety of technologies allowing such valorizations have been assessed and compared in a complementary report, and comprise:

- several electricity generation technologies, including gasification and powerplants
- fossil fuel substitution in industrial furnaces such as cement plants and brick kilns
- introduction of parboiling processes
- production of briquettes for small scale furnaces and cooking
- animal feed
- construction materials

VII. *Equipment modification*

Equipment modifications have been proposed in almost every country regarding high electrical consuming equipment (motors). Replacing current motors with high efficiency or variable speed motors would provide significant electricity savings, but need to take into account the depreciation of existing equipment and the investment capacity of the mills. Other equipment modifications comprise modernizing the lighting system, improving the electrical network, or installing a conveyer-belt system.

Other modifications such as improving the storage of rice can significantly improve the product quality and the overall process efficiency by reducing losses.

VIII. *New technologies*

The introduction of new technologies in rice milling is closely related to the recovery of by-products such as rice-husks.

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