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

Industrial Waste Minimization for Low Carbon Production

Coffee Sector Assessment

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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.

Acknowledgements

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Executive summary

With 6.7m tons of coffee produced annually in 1998-2000 and coffee ingestion being about a third of that of tap water in North American and Europe it is certainly one of the most produced and consumed commodities in the world.

Because coffee production cannot rely on automation – therefore hindering the prospects of great technological advances – it is a very labour-intensive sector, mostly handled by small independent farms. This high level of human capital relies heavily on coffee prices, which makes the sector highly vulnerable to market fluctuations.

The processing of coffee generates significant amounts of organic waste, as about 400kg of pulp and only 160kg of exportable green beans are generated out of 1t of fresh berries. In addition, the processing of coffee consumes important volumes of water and energy.

Implementing RECP options at processing level would enable producers to add value to their product while substantially bringing down production costs.

However, constraints intrinsic to the sector, such as the seasonality of coffee growing and the remoteness of a multitude of small producers, pose as many barriers to the implementation of viable RECP options.

This report is structured along three main parts.

Part I focuses on describing the coffee 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 an annex document (« Detailed description of RECP solutions in the coffee sector »).

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 coffee 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 an annex document (Annex documents to the coffee sector assessment, Annex B).

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Part 1. Industrial processes

1.1 Botanical and agricultural aspects

1.1.1 Coffee tree species

There are two main coffee species grown for commercialization and consumption. In general, Arabica beans are more aromatic and fruity, which grants them a higher quality and price. Robusta beans are generally considered as lower-quality coffee, thus selling for a lower-price. This difference in quality and, therefore, trade price is due to the fact that the Robusta coffee is easier and cheaper to produce. Indeed, while Arabica beans are delicate, susceptible to pest infections and require cool subtropical climates, Robusta beans grow on hardier plants, are less subject to plant diseases and have a better yield per acre with lower costs of production.

Arabica (Coffea Arabica)

The coffea arabica plant is a small tree or shrub with small glossy leaves and white fragrant flowers. Wild plants grow to be 5-10m tall and have an open branching system. Arabica grows best between the altitudes of 600-2000m, in cooler climates (15-24°C), and in areas with a yearly rainfall above 1000mm. Arabica plants do not require as much exposure to sunlight as Robusta plants, but also tend to be more prone to diseases such as rust, dry branch, dry fruit and pink disease (Practical action, 2002) (Roldan-Perez, 2008).

The coffee tree typically blossom following the first rain showers, after which it takes 9 months (210-240 days) for the cherries to ripen (Ecocrop FAO, 2007). It can take up to four years for Arabica trees to produce a harvestable crop and they may not reach full production levels until they are six to eight years old. They tend to produce relatively moderate yields - on average 1.5 tons of clean dried beans per hectare - for a period of 30-40 years (Ecocrop FAO, 2007).

The fruit, a drupe - often referred to as a “cherry” - is 10-15mm in diameter and ripens to a dark red or purple fruit that usually contains two coffee beans. Though Arabica coffee has a lower caffeine content (1-2%) than Robusta, it is known for its superior flavor, aroma and quality (Practical action, 2002) (Roldan-Perez, 2008). Its average market price is also the double of Robusta market price (Rathinavelu, 2005).

Arabica coffee accounts for about 65% of global coffee production. In 2007-2008, Colombia produced 12.4 million out of the 70 million bags of Arabica production worldwide. In Vietnam, only 10% of the coffee produced is Arabica, but government programs try to promote its expansion, especially in the North Uplands region (Roldan-Perez, 2008).

Robusta (Coffea canephora)

The coffea canephora plant, in its many varieties, grows to a 2-9m robust tree or shrub that thrives in hotter (24-29°C) lowlands, at altitudes below 900m.[9] Compared to Arabica, Robusta is less susceptible to diseases, is easier to grow and process, and has a higher crop yield (Ecocrop FAO, 2007). However, it is more sensitive to lower temperatures (below 5°C) (Ecocrop FAO, 2007). Once planted, Robusta trees begin to produce harvestable fruit within 3 to 4 years after being planted and have relatively high yields - around 2.2 tons of clean dried beans per hectare on average, for a period of 20 to 80 years (Ecocrop FAO, 2007).

Robusta cherries are small and red when ripe. Robusta coffee has twice the caffeine content of Arabica (2-4%) but is typically considered lower quality with an inferior taste (usually with a bitter, woody flavor) and is therefore sold at around half the price (Roldan-Perez, 2008). Also, Robusta beans are often used in the production of instant coffee (Practical action, 2002).

Robusta represents 35% of the global coffee production. In 2007-2008, Vietnam, which has recently overtaken Brazil as the world's largest producer of Robusta, accounted for 18 million out of the 45.4 million bags of Robusta produced worldwide (Roldan-Perez, 2008).

1.1.2 Coffee bean characterization

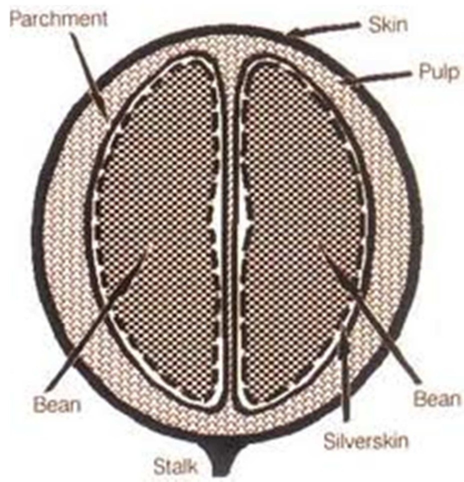

Figure 1 - Detailed drawing of a coffee bean (Murthy, 2012)

The **skin (*exocarp*)** and **pulp (*mesocarp*)** - collectively referred to as the "pulp" - form the outermost, fleshy layer of the cherry. It makes up for 30% of the cherry's dry weight (Murthy, 2012). "Coffee pulp is essentially rich in carbohydrates, proteins and minerals (especially potassium) and it also contains appreciable amounts of tannins, polyphenols and caffeine. The organic components present in coffee pulp (dry weight) include tannins 1.80–8.56%, pectic substances 6.5%, reducing sugars 12.4%, non-reducing sugars 2.0%, caffeine 1.3%, chlorogenic acid 2.6%, and caffeic acid 1.6% (Murthy, 2012).Coffee pulp is the first part of the cherry that is removed, either by hand (by squeezing the cherry until the encased bean pops out – see Figure 2) or by using a pulping machine (Murthy, 2012). Considering that for every 2 tons of coffee produced there is in average 1 ton of coffee pulp residues, there is a lot of potential in reusing this by-product (Murthy, 2012).

Figure 2 - Cherry Squeezing (FAO, 2013)

Once separated from the pulp, the bean (endosperm) is still covered by two layers: the parchment and the silverskin.

The **parchment (*endocarp*)**, also known as the "husk", is composed of 24.5% cellulose, 29.7% hemicelluloses, 23.7% lignin and 6.2% ash (Murthy, 2012)." The coffee husk, obtained during dry processing, encloses the coffee bean and make up for about 12% of the berry on a dry-weight basis (Murthy, 2012). "About 0.18 ton of husk is produced from 1 ton of coffee fruits" (Murthy, 2012). Husk is typically reused in coffee processing as a biofuel during the drying stages.

The **coffee silverskin (*epidermis*)** is a by-product that is obtained from the coffee bean during the roasting process. It contains a high concentration of soluble dietary fiber (86%) with a high antioxidant capacity. Such characteristics are probably due to the high level of phenolic components. The main components of these fibrous tissues are cellulose and micellulose (Murthy, 2012). Along with proteins, the monosaccharides present in the silverskin are glucose, xylose, galactose, mannose and arabinose (Murthy, 2012).

1.1.3 Coffee harvesting

As mentioned before, a typical coffee plant usually starts to produce fruit 3-4 years after it is planted. It produces cherries 6-9 months after blossoming - a process that is generally triggered by rainfall.[6] There is usually only one harvesting season per year, but in some cases (in Colombia for example) there are two (Roldan-Perez, 2008). There are two styles of picking: strip picking and selective picking.

Strip picking involves harvesting the entire crop at once. This method is much faster and can be done manually or mechanically (when the proper conditions are met - level ground for example). Strip picking leads to yields that contain a larger amount of green cherries, which are subsequently separated from the ripe cherries. Strip picking is most often used when harvesting Robusta (Practical action, 2002).

Selective picking involves picking only the ripe cherries and leaving under-ripe cherries on the tree to be picked at a later date. Workers do this manually. While being painstaking work, it is an important part of creating a higher quality end product and is typically used when picking Arabica (Practical action, 2002).

One of the most serious problems with coffee harvesting has to do with premature picking of an under-ripe crop, mostly justified by fear of theft. Ideally, the coffee cherries should be picked when they are bright red all over and the bean can be squeezed out of the pulp by applying light pressure between finger and thumb. Green cherries, on the other hand, cannot be properly pulped and contain overly bitter beans (Practical action, 2002).

1.2 Coffee processing

Coffee processing can be divided into two parts: **primary** and **secondary**. Primary processing involves the conversion of harvested coffee cherries into green coffee beans (raw, unroasted coffee) and is always done in the producing country (Murthy, 2012). Secondary processing is the transformation of green coffee beans into final consumer products. This includes processes such as roasting, grinding and instant coffee production. Secondary processing is almost always carried out in the consuming country (Murthy, 2012). A chart presenting the amount of value added in USD along each stage of the production chain is available in an annex document[1].

There are two types of primary processing: dry ("natural") method and wet ("fermented and washed") method (Practical action, 2002). Dry processing consists of two phases: drying the fruit and removing its outer layers to reveal the green bean. Wet processing consists of three stages: a) removing the pulp and mucilage and washing, b) drying and c) removal of the parchment and silverskin (Ecocrop FAO, 2007). Wet processing is believed to produce a higher quality product, though there are some who prefer dry-processed coffee due to its fuller flavor (Practical action, 2002).

[1] Annex documents to the coffee sector assessment, Annex E.

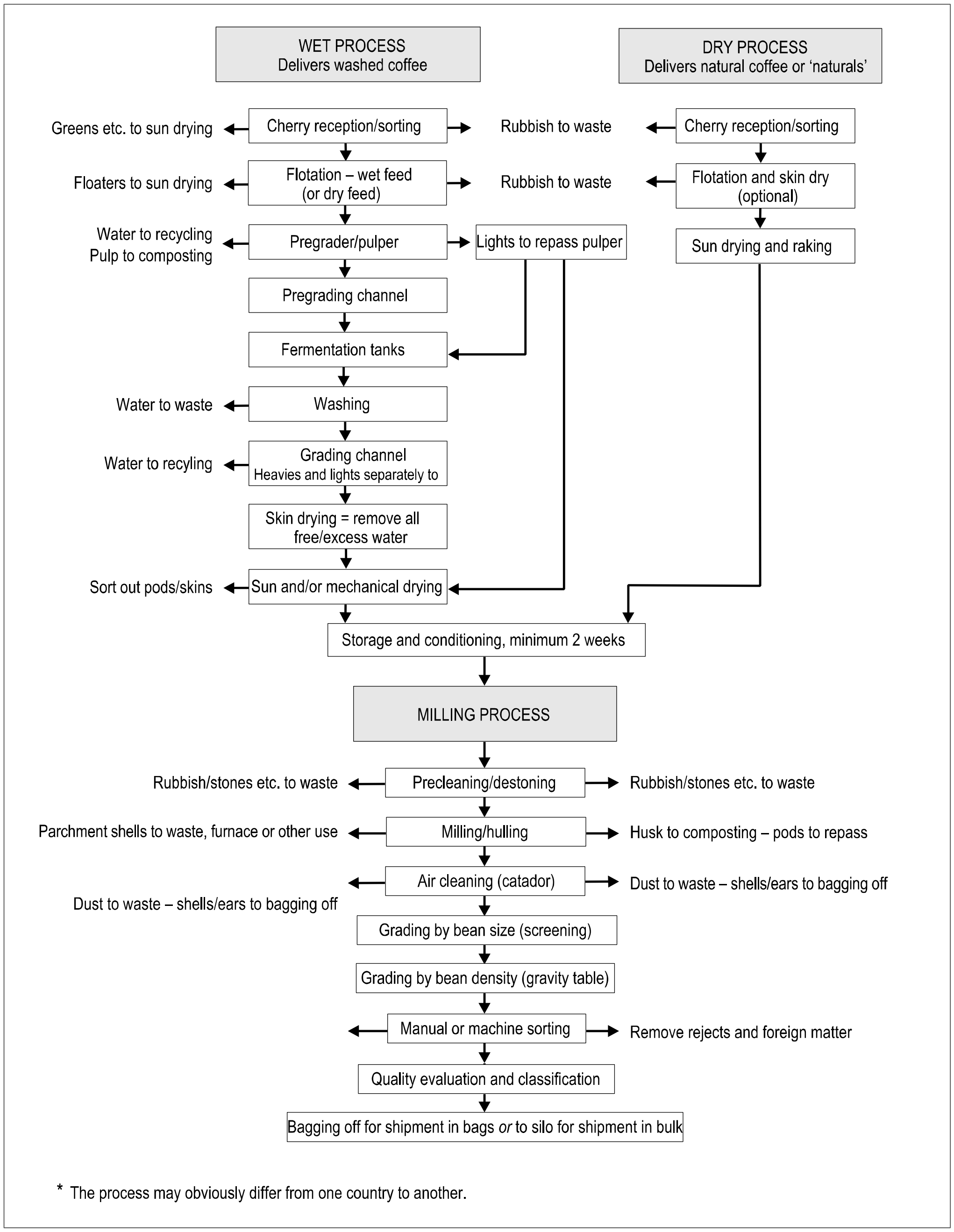

Figure 3 - Process flow for both wet and dry processing and the milling process, including the by-products associated with each step (Jan van Hilten, 2011)

1.2.1 Primary processing

Dry Processing

Dry processing is the oldest method of coffee processing and is typically used in countries with limited access to water resources. Dry processing can be done either by laying out cherries onto flat surfaces to dry in the sun or by using an artificial dryer. The latter is usually found in more advanced installations. The drying process is done before the removal of the pulp and mucilage.

I. Solar drying

Coffee cherries are sun dried right after the harvest by spreading them out evenly at depths of less than 8 cm on clean, dry floors, on mats or on drying tables (Murthy, 2012) (Practical action, 2002). Cherry beds should be raked and frequently turned to prevent fermentation, mold and discoloration. Cherry moisture needs to reach 10% to be considered dry. This typically happens within 12 to 15 days under bright weather conditions (Murthy, 2012). "The cherries are considered as dried when a fistful of coffee produces a rattling sound when shaken (Murthy, 2012)." Problems associated with this method include dust and dirt blown onto the beans, rainstorms that can soak the produce very quickly and theft.

II. Artificial dryers

Some of the more sophisticated coffee farms - or simply those located in more humid regions where sun drying is impossible for most of the year - are equipped with large drying tumblers that rotate the beans while blowing hot air over them (Grumpy Mule). Drum drying can be problematic because, if not closely monitored, beans can quickly be damaged and take on an unwanted taste (Grumpy Mule).

III. Hulling

In dry processing, hulling refers to the removal of the skin and pulp (pericarp and mesocarp) either by hand, using a mortar and pestle, or in a mechanical huller (Murthy, 2012). Generally, mechanical hullers consist of a steel screw. Its pitch increases as it approaches the outlet and therefore removes the pericarp. (Practical action, 2002).

IV. Cleaning

Cleaning is typically done by winnowing – a manual process by which coffee is sifted so that usable beans are separated from broken beans or unwanted pieces of pulp that may be left over (Murthy, 2012).

Wet processing

Wet processing involves removing the pulp and mucilage before drying the parchment coffee. The coffee is then hulled and cleaned before being shipped to roasters. Compared to the dry method, the wet method requires the use of specific equipment as well as significant quantities of water.

I. Pulping

Pulping is the separation of the beans from the pulp (Murthy, 2012). Freshly harvested cherries can be pulped by mortar and pestle or by using mechanical pulpers. The wet method for coffee processing requires proper pulping equipment and clean water.

The fruit is first siphoned into the pulper in a uniform manner. This ensures that the pulp is properly removed and prevents cutting the parchment beans as well as choking the pulper. Sieving the pulped parchment eliminates any unpulped fruits and traces of fruit skin. In general, water recirculation is done at pulping sections and this recirculated water can be used for one day. This is due to the fact that the quality of water quickly deteriorates after that time limit (Central pollution control board. Ministry of Environment and Forests, 2006).

There are several kinds of pulping machines. Drum pulpers are made up of a rotating drum (a punched sheet surface) and an adjustable breastplate. The coffee cherries are pulped between these two components. Because the size of the beans can vary, the distance between the drum and the breastplate must be adjusted in order to avoid damaging the beans when the pulp is removed. In the mechanical sense, drum pulpers can be operated either manually, attached to a bicycle, or – in the case of larger scale units – are motorized (Practical action, 2002).

Figure 4: typical manual drum pulper (source: http://espressocoffee.quora.com/)

Disk pulpers work in very much the same way except that, instead of being squeezed against a breastplate, the cherries are pressed against a rough spinning surface (Practical action, 2002).

II. <u>Mucilage removal</u>

Once the pulp is removed, a layer of mucilage remains on the parchment coffee. Mucilage is a water-soluble gel made up of pectin and sugar. It can be removed using chemicals, warm water or mechanically using an “agua pulper”. Most small-scale production sites use fermentation. Fermentation requires the parchment to be soaked in buckets or tanks until natural enzymes and bacteria break down the mucilage. The coffee should be regularly stirred and beans occasionally tested. The beans are ready once they feel rough rather than slippery. All the beans should then be washed in order to prevent “off” flavors from developing (Practical action, 2002). In the case of Arabica, this process can last 24 to 36 hours. For Robusta, 72 hours are still insufficient. It is therefore recommended that the mucilage be removed via alkali treatment or by means of friction to obtain better results (Central pollution control board. Ministry of Environment and Forests, 2006).

III. <u>Drying</u>

This drying process is very similar to the natural method, except that it is done with demucilaged parchment coffee instead of freshly picked cherries. The parchment coffee should be laid out after being washed and then dried slowly, to prevent cracking, until its humidity is brought down from 50% to 10% (Central pollution control board. Ministry of Environment and Forests, 2006); (Practical action, 2002).

IV. Hulling

After being dried, the coffee should be allowed to rest for 8 hours before being hulled with a mortar and pestle or in a huller. This process removes the layer of parchment around the coffee thus leaving behind “green coffee” (Practical action, 2002).

V. Cleaning

Generally, the hulled coffee is cleaned by winnowing. It is then bagged and ready to be sent to roasters.

1.2.2 Secondary Processing

Roasting

The coffee’s final flavor is largely dependant on how the beans are roasted - most notably on time and temperature. In general, beans should be roasted at about 200°C (Practical action, 2002). The degree to which the beans are roasted can usually be assessed visually by observing the white line dividing the two sides of the bean. When it turns brown, the beans are properly roasted (Practical action, 2002). Coffee beans can be roasted in a saucepan as long as they are continually stirred. They can also be roasted in sand, which provides even more heat. Utilizing a roaster will lead to even greater results. The most basic roaster involves rotating a tin can over a fire. Various roasters exist that are more appropriate for large-scale operations.

Grading

Higher quality products are often graded. Coffee is graded by size, shape, odor, density and color. For small-scale units this is best done by hand.

Grinding

Grinding adds value to a product. However, it can also lead to difficulties in terms of assessing the coffee’s quality. The fear of alteration can lead to market resistance towards ground coffee. This market resistance can only be overcome by consistently producing a good product. There are essentially two types of grinders - manual grinders and motorized grinders (Practical action, 2002). Both types of setups require prior knowledge of the fineness of coffee grounds desired by the customer.

I. Manual grinding

There are many manual grinders that can be used to grind coffee.

An experienced operator can grind about 20kg in eight hours. However, this work is repetitive and hard and is often made easier by attaching a treadle or bicycle to the grinder. With this system, a worker can grind about 30kg in a day.

Small-scale production sites (up to 100kg/day) only require a series of grinders. Larger scale production units, however, need a motorized grinder (Practical action, 2002).

II. Motorized grinding

There are several types of motorized grinding: horizontal plate, vertical plate or hammer mills. In general, a grinding mill has to be placed separately in a well-ventilated room due to dust.

Packaging

I. *Packaging materials*

Packaging requires polypropylene. Polythene cannot be used as the flavor components diffuse through it. The use of laminates is popular but more expensive.

II. *Simple sealing*

Simple sealing can be accomplished by folding the plastic over a hacksaw blade and running a flame over it. However, when done manually, the handling of the hot blade can quickly become uncomfortable for the operator.

III. *Sealing machines*

Using a sealing machine is faster and produces a much tidier finish. Sealing machines with timers are desirable in order to prevent overheating of the seal. However, once again the economic barrier to the acquisition of such equipment is problematic for small-scale producers.

Storage

A well-designed and secure storage facility must have low temperatures, low humidity and be free from pests. Only dry products should be kept in storage in order to keep humidity levels as low as possible. The stored product should be checked regularly to make sure it hasn't absorbed too much moisture, in which case it should be dried again, therefore inducing further use of energy and time. To prevent pests from contaminating the product, the roof should be completely sealed, netting should be placed over the windows and the doors should be close-fitting (Practical action, 2002).

1.3 Major environmental concerns of coffee processing

1.3.1 Resource consumption

Though not much research exists on the energy (typically in liters of diesel fuel) and water consumption tied to the various types of coffee processing, three preliminary conclusions can be drawn from the information at hand. First, the wet method is more energy and water intensive than the dry method. Second, as part of the wet method, the mechanical drying process is generally the most energy-consuming. Third, instant coffee production also demands great amounts of energy.

Small-scale coffee production sites remain rather limited in terms of their resource consumption. Considering small-scale producers tend to employ the dry method, the energy used to dry and hull is mostly human- and solar-based. Knowing this, it is safe to say that dry method of processing could stand to gain more from improved waste management than energy management.

On the other hand, when taking into account the approaches of large plants that mechanically produce green coffee via the wet method, it can quickly be observed that conventional coffee production is extremely energy and water intensive. Additionally, a plant that relies on mechanical pulpers and driers involved in the wet method of production is bound to consume more energy per ton of cherries produced. In fact, it can be said that the mechanical drying stage is the most energy demanding - accounting for 80% of the total energy required. In terms of water consumption, international sources claim that depending on the production site, anywhere from 1 to 15 m^3 of water are consumed per ton of processed coffee cherries (GTZ, 2002).

Instant coffee production, due to its highly technical processing mechanisms, also consumes a large amount of energy. The spray method seems to be the most costly, both economically and energetically speaking and processing plants that employ such a method stand to benefit greatly from raised efficiency measures.

With regards to environmental degradation and resource preservation, wet processing poses a serious threat to fresh water reserves. Therefore, the sustainability of the coffee industry hinges mainly on further research into ways that permit a reduction of water consumption in coffee processing.

1.3.2 Waste production

In many coffee-producing countries, the waste and by-products resulting from the different stages of various processing methods constitute a source of severe contamination (Murthy, 2012). Dry processing is understandably the least polluting because it does not involve the use of water. On the contrary, the wet method creates a large amount of effluents, which have the potential to damage the environment and pollute waterways. Both processing methods produce a substantial amount of solid waste, which can also be harmful to the environment if not properly disposed of.

Solid waste from coffee processing includes pulp, husk, silverskin and spent coffee. The pulp, which accounts for approximately 30% of the entire cherry's dry weight and is produced at a rate of 1 ton (dry matter) for every 2 tons of coffee produced (or 2.7 tons of fresh pulp for every ton of coffee), is the primary by-product and poses serious disposal issues due to its high moisture content and tendency for putrefaction (Cenicafé, 2010; Murthy, 2012). Furthermore, coffee pulp contains caffeine, free phenols and tannins (polyphenols), which are known to be very toxic to many life processes. There are many ways to reuse the various solid by-products accumulated during coffee processing and they will be introduced in the following section.

With regards to effluents from wet processing, problems occur when large amounts of organically rich effluents (mostly due to the pulping and demucilaging processes) end up in bodies of water, thus greatly exceeding the self-purification capacity of natural waterways. The sugars contained in the mucilage will quickly ferment to alcohol and CO_2. The alcohol is then quickly converted to acetic acid. During the fermentation process, the acidification of sugars will drop the pH to around 4 or less and the digested mucilage will be precipitated out of the solution, thus building a thick crust - black on top and slimy orange/brown underneath - on the surface of the wastewater. If not separated from the wastewater, this crust will quickly clog waterways and further contribute to anaerobic conditions in the waterways (Murthy, 2012). Other substances found in coffee wastewater are toxic chemicals such as tannins, alkaloids (caffeine) and polyphenols. These tend to make the conditions for biological degradation of organic material in the wastewater more difficult.

Figure 5 - Coffee by-products obtained during coffee processing (Murthy, 2012)

1.3.3 Use of by-products

The various by-products resulting from coffee processing can be valorized through their reuse in various applications. When combined, the pulp and husk account for approximately 45% of the cherry's dry weight and are rich in nutrients. Nevertheless, the pulp and husk are generally considered too toxic to be used for purposes other than in the production of fertilizer, livestock feed and compost, due to the high levels of tannins they contain. However, treatment tests to decrease the toxicity of the pulp have proven effective and may allow for a wider range of uses.

The various ways of by-product valorization are detailed in the following table.

Table 1: Coffee processing by-products and their applications (Murthy, 2012)

By-product	Applications
Coffee pulp	Mushroom production Composting Food commodities Polyphenol extraction Anthocyanins Animal feed Biosorbents
Coffee husk	Citric acid Gibberellic Vermicompost Flavor Particle board Biosorbents Tannase
Coffee pulp and husk	Animal feed Amylase Protease Pectinase Xylanase Fructooligosaccharides and beta-fructofuranosidase Ethanol production Biogas

	Aroma
Coffee silver skin	Phenolic compounds Dietary fiber
Spent waste	Animal feed Ethanol Coffee oil Adsorbent Activated carbon Carbonaceous materials Antioxidants Spent coffee extracts Fuel, biodiesel, bioethanol

Currently, commercial projects exist for energetic by-product valorization such as the production of biogas out of coffee pulp and coffee wastewater or the use of coffee ground products as fuel. Coffee husk is also used directly as fuel (mainly for coffee drying but also in other industries) with the advantage of it already being dry as opposed to coffee grounds which are wet after extraction and are used almost exclusively in instant coffee production facilities.

Biogas presents the advantage of combining the treatment of highly polluting by-products (coffee pulp and wastewater) and the production of energy that can be used in the transformation process (roasting for example). Regarding other types of valorization, mushroom, compost, lombricompost and animal feed production are already commercially implemented. These applications are further detailed in the project identification forms.

However, the extraction of chemical compounds such as acids, dyes, anthocyanins, enzymes etc. are not yet being commercially implemented but exist in academic research since the extraction processes require significant technical equipment and are rather expensive.

The production of enzymes, such as pectinase, by using fungi shows significant economic potential (in addition to that, pectinase can be valorized in coffee production since it can improve the rate of mucilage degradation) and should be further developed.

Thus, these projects need to be further investigated in order to maximize the benefits of by-products valorization.

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.

For the purpose of clarity, the following table will present the different projects and give a general outline of them. Detailed reports on the projects can be found in a separate annex document « Detailed description of RECP solutions in the coffee sector ».

Table 2 : RECP projects implemented in various locations

Project title	By-product use	Technology	Outcome	Country	Stakeholders	Comments
Smallholder coffee processing design using wet technology based on clean production	Pulp	Water minimization, production of biogas	Improvement of coffee bean quality Water minimization Reduction of greenhouse gases emissions Production of compost, livestock feeding, briquette, mushroom and particle board	Indonesia	Producers/processors	Preservation of product quality Added value of solid waste utilization
Water minimization and anaerobic treatment system for the pulp waste water with biogas production	Pulp, water	Water minimization, water recycling, biogas	Improvement of coffee beans quality Water minimization Reduction of wastewater pollution content Reduction of greenhouses gases emissions	Costa Rica	Producers/processors (Coope Libertad)	Costa Rica requires RECP technologies in order to overcome low-prices
Managing wastewater from coffee processing	Water	BeColSub (demucilaging machine)	Reduction of the amount of water required to process and clean coffee Reduction of potential contamination	Hawaii, U.S.A. and Colombia	Producers/processors, Universities and institutions/National Associations	
Pilot wastewater treatment system for semi-washed coffee including finish fermentation and washing	Water	Acidification pond, neutralization tank	Reduction of water consumption Reduction of wastewater pollution Reduction of BOD in the biogas reactor	Vietnam	Processors, International Development Organizations, Private Consulting Offices	Implementation requires space, skilled labor
Better coffee with less water – cleaner production applications in a mountaintop coffee producing farm	Water	Creation of a closed loop for water	Reduction of water consumption Reduction of water pollution Valorization of by-products and production of fertilizer Potential of gas usage reduction by 25%	New South Wales (Australia)	Producers/Processors: Mountain Top Coffee (MTC), National Department of Environment and Climate Change	All the coffee produced in Australia uses the wet processing method
Cleaner production	Water, husk, pulp	High efficiency pulpers	Reduction of water consumption	Salvador	Producers/processors, National	Salvador is a large coffee producer

applications guide for coffee processors in Salvador		Endless screw to transport the removed pulp Production of energy with by-products	Reduction of wastewater pollution Reduction of energy consumption		Associations, International Development Organizations	
Effect of mechanical cooling in the quality of the stored coffee in bulk	-	Storage silos	Improvement of bean quality	Colombia	Producers/processors	Provides the improvement of coffee storage
Energy recovery from coffee husk in cement plants	Husk	Energy from husk	Reduction of fossil fuel consumption Reduction of coffee waste Reduction of greenhouse gases emissions	Uganda	Lafarge Hima Cement Plant	Hima cement invested in coffee production in exchange for husk to run the plant
Solidaridad-Essent pilot project	Husk	Energy from husk	Reduction of fossil fuels consumption Elimination of waste	Brazil, Holland	Essent Energy Company (NL), Solidaridad (ML, NGO), Fair Biomass Brazil	International cooperation Providing electricity to external people
Mushroom growing project in Colombia	Composite of coffee by-products	Fertilizing use of by-products	Production of edible products Elimination of waste	Colombia	Zero emission research initiative (ZERI), National Center for Coffee Research (Cenicafé), National Federation of Coffee Growers of Colombia, Agropolis IDRC, Office of the Mayor and Chamber of Commerce of Manizales	Coffee prices significantly decreasing 99% of by-products go to waste
The use of biomass residues in the Brazilian soluble coffee industry	Soluble coffee by-products Coffee grounds		Reduction of fossil fuels consumption Elimination of waste	Brazil	Soluble coffee production plants	Exit gases from the boiler also used to dry the grounds
Biogas production of coffee pulp	Pulp	Biogas reactor	Reduction of fossil fuels consumption Elimination of waste	Costa Rica	Axp, Ernst Basler + Partner (EBP), Swiss Cooperation (DDC and REPIC), Zurich University of Applied Science (ZHAW)	The plant cannot be run all year round
Research paper: Tratamiento anaerobio de las aguas mieles del café **Project: Sembradores de Paz**	Water	Anaerobic modular treatment system	Reduction of water pollution	Colombia	CENICAFE, Agencia Espanola de Cooperacion Internacional, Gerencia Tecnica de la Federacion Nacional de Cafeteros de Colombia, Comité Demartamental de Caffeteros de Magdalena	Cheap and easy to run

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 emerged and are presented in the following table.

Table 3 : Main characteristics of worldwide identified RECP projects in the coffee sector

	Main transversal bottlenecks	Key success factors
All Projects	• Lack of skills and manpower • The minimization of water use in the wet process leads to an increase of the polluted content of the waste water.	• Setting up of capacity-building programs, training courses • Development of technology adapted to local skills, and machinery availability • Economic viability of the proposed technology, low-cost technology • Communication and marketing programs • Technology assessment performed before setting up commercial projects • Laws and incentives that promote the valorization of by-products and wastewater treatment.
By-products to energy projects	• Coffee does not grow all year round thus limiting energy production period capacity.	• Governmental incentives to reduce the amount of produced wastewater combined with the need to reduce production costs forces considering by-products as energy source.

1.5.2 Process-oriented prioritization

Drawing on the previously observed results, it appears that intervention at the processing stage would produce the best results since it is the most energy-demanding phase of coffee production, as well as the one generating the most by-products.

With the conjunction of these two characteristics, the following technical recommendations focus on the processing and post-processing phases in order to better implement RECP technologies.

- Production of energy out of coffee grounds coming from soluble coffee plants
- Production of biogas out of wastewater and coffee pulp
- Promotion of dry processing (instead of wet processing)
- Reduction of water consumption by recirculation
- Modular wastewater treatment systems

1.5.3 Projects to investigate

Since the projects identified were mostly focused on wastewater treatment and biogas production, several areas of reflection still need to be further investigated, namely:

- Production of building material (such as particle board)
- Production of animal feed

In addition to that, several research studies have been carried out to extract certain compounds out of coffee by-products such as enzymes, dietary fibers, aroma, anthocyanins etc. as well as ethanol, which are not presented in the project identification forms.

These are still at the study level and do not seem to be commercially implemented yet.

Part 2. National Contexts assessment

2.1 World coffee production and market

While coffee growing is quite limited to specific regions with suitable agro-climatic, topological and pedological features making it a regional industry, its consumption is one of the most widespread in the world.

Over 90% of total coffee production takes place in developing countries and around 25 million producers rely on coffee for a living. However, as opposed to rice, the final conditioning and trade of coffee is mostly done in a place other than that of production. Indeed, while rice is generally entirely treated and traded where it is grown, this is not the case for coffee. Switzerland is a very graphic example of this as, despite not having any local production, around 50% of the total worldwide coffee production is traded in Switzerland.

Table 4 - World coffee production evolution by type (millions of bags) (ICO, 2013)

Coffee Year	**02/03**	**03/04**	**04/05**	**05/06**	**06/07**	**07/08**
World	114.1	112.5	115.0	117.0	118.4	123.4
Arabicas	73.2	69.7	72.3	74.2	73.7	78.0
Brazil	29	25.9	27.8	28.4	28.4	30.3
Colombia	11.9	11.2	12.0	12.3	12.2	12.4
Other America	21.1	21.5	20.2	22.4	21.6	23.4
Africa	6.9	6.8	7.9	7.3	7.7	8.5
Asia and the pacific	4.3	4.2	4.4	3.8	3.8	3.4
Robustas	40.9	42.8	42.6	42.8	44.7	45.4
Brazil	9.6	8.1	8.3	9.3	9.0	10.7
Other Latin America	0.3	0.4	0.5	0.5	0.5	0.4
Vietnam	11.6	15.2	14.2	15.5	15.5	18.0
Indonesia	5.9	6.2	7.4	6.8	6.8	5.7
Other Asia and Pacific	5.4	5.5	5.4	5.9	5.9	4.3
Côte d'Ivoire	3.2	2.7	2.3	2.5	2.5	1.5
Uganda	2.6	2.2	2.1	1.8	1.8	2.2
Other Africa	2.4	2.6	2.4	2.7	2.7	2.6
Share of global production						
Arabicas	64.2	62.0	62.9	62.2	62.2	63.2
Robustas	35.8	38.0	37.1	37.8	37.8	36.8
Source: ITC/ICO (2008)						

Because coffee production cannot rely on automation – thus hindering the prospects for great technological advances – it is a very labor-intensive sector. This high level of human capital relies heavily on coffee prices, which makes them highly vulnerable to market fluctuations.

A pressing issue is the drop in the price of Arabica coffee over low-quality Robusta coffee, illustrated perfectly by **Vietnam**'s dramatic rise in production (see Table 4). While consumption in the United States, Europe and Japan remains quite flat, it is steadily growing in faster-developing countries such as China, Indonesia and Brazil. However, in order to satisfy these new consumers, Robusta is the coffee mainly used in this growing demand. Not only is this justified by lower prices for Robusta, but also because its production requires less human surveillance and is resistant to most diseases affecting coffee crops. This in turn affects market prices with a flooding of lower-quality Robusta, the production of which is done extensively and at lower costs. This is a difficult position to overcome for Arabica producers in **Colombia**, Brazil and other South and Central American producing states that need to deal with retail problems as well as production issues.

Despite the existence of organizations that manage the output of coffee at the international level, coffee growing nonetheless remains an enterprise attached to its national and regional context. The main intergovernmental coffee organization is the International Coffee Organization, set up under the auspices of the United Nations in London in 1963. Its widespread influence and domain of activity cover 97% of the world's coffee producers and 80% of consumers (International Coffee Organization, 2010). Its activities try to ensure a strengthening of the coffee sector and the promotion of sustainable expansion. However, coffee prices are still not decided by producers or distributors, but rather in New York and London, thus creating totally separate processes from production to final product sale. Because most coffee producers are small independent farms (Figure 6), this has dramatic consequences on them, since they do not own and have access to funding at times when their coffee is sold at lower prices. Despite the fact that most processes are conducted directly by the farmers, their influence on the final price is nearly negligible.

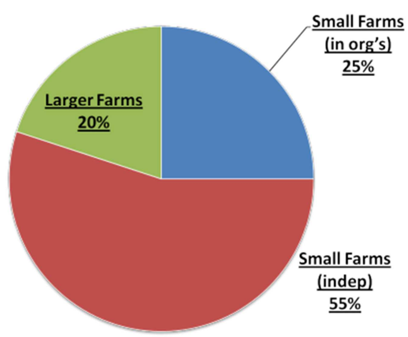

Figure 6: Share of coffee producers size (Zamora, 2013)

World coffee production is forecast at 146m bags in 2013/14, down by 4.4m bags from the previous year. According to the United States Department of Agriculture (USDA, 2013), this slowing of production is mainly due to the entering of Brazil's Arabica trees into the off-year of the biennial production cycle, as well as Central America and Mexico's still unresolved issues with coffee leaf rust. Such natural influences on the production of Arabica coffee could have great consequences on their producers who, despite its lower market value, might consider growing Robusta coffee which is more resistant to natural hazards.

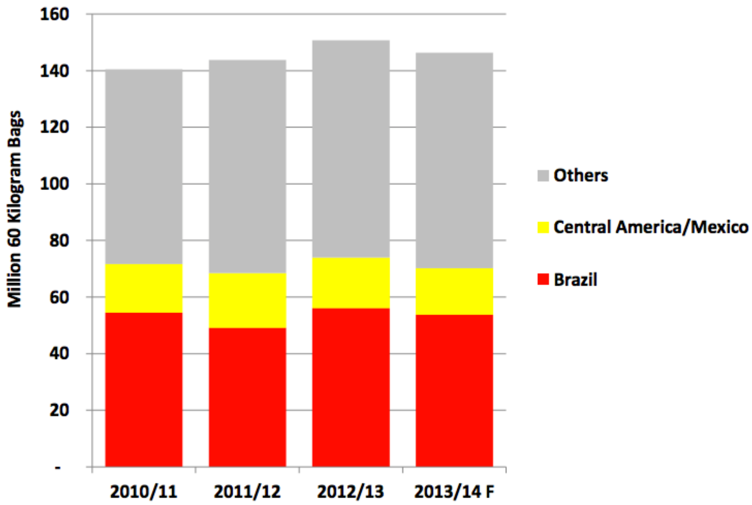

Figure 7: World coffee production (USDA, 2013)

Apart from natural influences, producers – notably small-scale – face several difficulties in the upcoming years:

- Rise in domestic consumption, with great consequences on poor and developing countries.
- Difficult access to financing with the slow recovery of institutions from the 2008 global economic crisis.
- Difficulty to remain independent in the face of shortage in funds and distribution markets.
- Arabica producers are losing ground over low-price Robusta producers because of periodical oversupply by the latter.

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

Table 5 : World Economic Forum's Global Competitiveness Index for Colombia, Peru, Vietnam and Cambodia

Vulnerability towards natural and market fluctuations requires a redefinition of coffee producers on the international scene. While it is quite difficult to intervene in market prices via national programs, it is possible to counter the effects of natural hazards through technological advances. With a high reliance on politics for development and stability, coffee growing is directly linked to the actual national and international context. To establish the degree of market openness and competitiveness, the World Economic Forum's Global Competitiveness Index (World Economic Forum, 2012) informs us on **Colombia, Peru** and **Vietnam**'s situation and highlights the main factors making business more difficult.

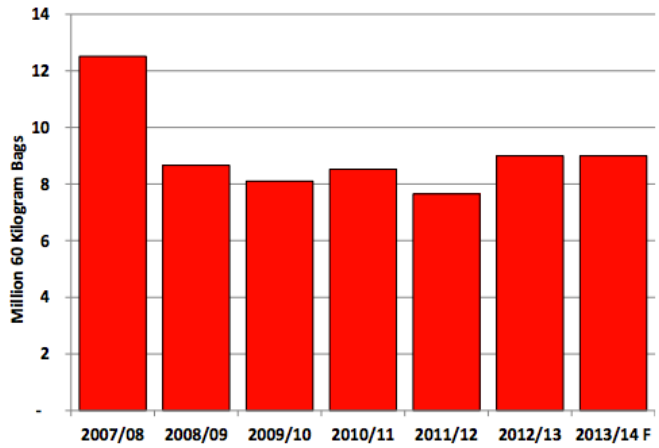

Figure 8: Colombia's total coffee production **(USDA, 2013)**

While coffee growing has different economic and social importance depending on the region, this context assessment will concentrate on the national level. By describing **Colombia, Peru** and **Vietnam**'s coffee production cycle, this report will look at the available opportunities for an implementation of RECP. Such program would empower the coffee growers to rely less on external funding while reusing waste generated during production to produce a sustainable supply of energy. More importantly, RECP would allow growers access to on-farm installations and facilities, necessary to enable them to add value to their product while substantially bringing down production costs. The potential for biowaste reuse is high as it is estimated that 1t of fresh berries generates about 400kg of pulp and only 160kg of exportable green beans (von Enden, 2002). However, a further consideration that needs to be taken into account is the seasonality of coffee growing, which determines the production of waste. Indeed, as the processing, and thus the accumulation, of organic by-products is limited to the harvest season, RECP technologies need to adapt to this timeframe and operate accordingly. Also, because some portions of by-products are already being used, notably to produce fertilizer, RECP technologies need to reassess and take into account the current use of biowaste.

With nearly 1m ha dedicated to coffee in 2011, Colombia has one of the largest coffee exploitations in the world with a harvested area of 739'414 ha (FAO, 2013). In 2012, it was the fourth largest producer of coffee after Brazil, **Vietnam** and Indonesia. **Colombia**'s market success is notably due to its high quality of Arabica coffee and its ability to provide high volumes at a steady quality. Exclusively producing Arabica, **Colombia**'s production was forecast at 9m 60-kilogram bags, equal to 2012 figures, and representing 5.65% of total world production. Despite a slow rise in production, levels are still far below the 2007/08 pre-crisis level of 12.5m bags. Also, the adverse effects of La Niña have facilitated the spread of coffee rust and coffee cherry borer. Such external effects on coffee production have necessitated governmental subsidies for growers that need to compensate for falling prices and the difficulty in recovering from natural hazards.

In 2011/12, **Peru** produced a total of 5.2m bags of coffee (USDA, 2013), exclusively Arabica. Despite a slowing of production in 2007 due to an unfavorable economic conjuncture, production has been on the rise in recent years. However, coffee rust, a type of fungus (La Roya, in Spanish) is severely compromising production, with mentions of 500,000 bags down from the last year's production (USDA, 2013). Despite media concentration on the impact of coffee rust on Central America, its adverse effects pushed **Peru** to declare a state of emergency in 2013 (Andina, 2013).

Vietnam, the second-largest coffee producer in the world, produced nearly 1.2m tons of coffee in 2011, totaling around 25.2m bags. **Vietnam** rose to the status of second world producer in 1999, surpassing **Colombia**. **Vietnam'**s production in 2012/13 is forecast at 24.8m bags, a slow decline from the previous year's result due to a dry start of the rainy season, followed by below-average precipitation. As the region grows fonder of coffee consumption, **Vietnam** is looking to conduct higher shares of its trade with neighboring countries. Recently, Nestlé opened a Nescafé factory worth CHF230m ($236m) in order to meet the growing regional demand for soluble coffee. Such development indicates a clear will from international companies and actors to get involved in Vietnam's phenomenal developments in coffee production.

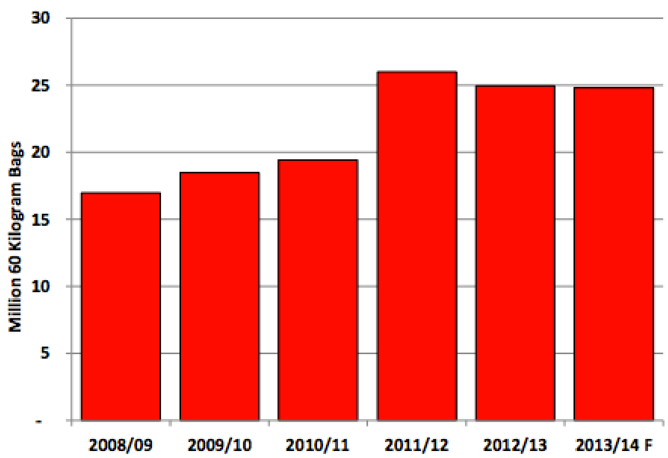

Figure 9: Vietnam's coffee production (USDA, 2013)

2.2 Stakeholder Overview

2.2.1 Coffee growers, technical and energy supply, biowaste

Colombia

While employing nearly 2.2m people (around 4.7% of the total population) in 2010, the coffee sector accounted for around 5% of Colombia's export value. Compared to other producing countries and to the final obtained results, the coffee sector employs a very large number of people. According to Federacafé, 64% of Colombia coffee growers are smallholders with less than a hectare of coffee. Despite being a majority in terms of human labor, they only account for 15% of total production (Federacafé, 2008). The majority of final produced coffee (45% of the total) is done by 5% of farms (Federacafé, 2008). In the bigger picture, it is estimated that 94% of farmers have less than 5ha of production. The main harvest period takes place between September and December and the secondary harvest period is between April and June (Cenicafé, 2010). The average yield was 633 kg/ha in 2011 (FAO, 2013). In December 2012, Colombia's Arabica export price was 131.32 $cents/lb, a much higher price than Vietnam's Robusta (83.72 $cents/lb for the same period; ICO). In 2012/13, Colombia exported most of its production, reaching 8.3m exported bags, out of a production of around 9m. In 2011, 7.1m of exported bags brought revenue of $2.8 billion. Despite its massive exports, Colombia still imported around 710,000 bags of coffee in 2012/13, mostly lower quality and instant coffee (USDA, 2013). In order to favor locally produced coffee, different ranges of taxes apply: 10-15% on imports of green coffee; 15-20% on imports of roasted coffee; 20% on imports of soluble coffee. However, taxes on imports from the Andean community are 0%. The most prominent development in recent years in coffee production and processing in Colombia has been the establishment of modern technologies, which has allowed a rise in production and value despite maintaining the same harvested area. Most of Colombia's coffee processing is done using the wet method. However, a 2002 CEDE study showed that around 15,000 coffee processing units used the 'Becolsub' method (more than 80% of the Colombian coffee producers), therefore reducing the use of water and the subsequent waste water normally generated when the wet method is used (Cenicafé, 2011). Derived from the Spanish Beneficio Ecologicos Sub-Productos, this method supposedly manages to reduce the amount of contamination in the water used to process the beans by 90% (Cuervo, 1997). Most of Colombia's energy use is oil, followed by hydroelectricity, natural gas and coal. The country relies on hydropower to provide the bulk of its electricity needs, creating opportunities for coal exports. The electricity supply in Colombia is managed and distributed via the National Interconnected System (SIN), covering around one third of the territory i.e. up to 97% of the population (World Bank, 2004). In 2010, Colombia produced 5m tons of residues and by-products from coffee production and processing. Of these residues, most were disposed of in the environment while some were used to elaborate compost and fertilizers. The revalorization of coffee pulp could contribute to providing around 20% of dairy cattle feed.

Peru

Extending over 405,000ha and accounting for 12% of the total cultivated area in Peru (FAO, 2013), coffee production also employed 750,000 workers (ICC) in 2010. Quality-wise, Peru's Arabica is of high quality, with 30% of the total production also being organic (expocafeperu.com). The harvest period depends on the region, and the average yield totaled 900 kg/ha in 2011. This relatively good yield result undergoes losses ranging between 17-37% in all processing operations. Of the 5.2m bags produced in 2011/12, Peru exported 5.1m and did not import any. The main destinations for exports were Germany

(34%), the United States (19%) and Belgium (16%). The most widespread method of processing is the wet method, used by at least 90% of producers (ICO, 2013). It is mostly small agricultural units of 10-80 ha that use the dry method of processing. Most of the industrial processing to obtain green beans is done in cities surrounding the major ports, with 10 processing companies making up the bulk of processed coffee. According to the International Energy Agency (International Energy Agency) 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, the government estimated national coverage in 2012 at 87.2% (Republica del Peru, 2012). However, according to a manufacturer of coffee processing machines, it appears that around 70% of coffee producers (accounting for around 50% of the total coffee production) do not have easy access to grid electricity, hence forcing them to use petrol generators (IMSA, 2013).

Nearly all waste is disposed of in the environment, either by burying it or by directly unloading it into water streams, while a small part of by-products and waste is used for revalorization via the creation of fertilizers. With water consumption at 10 liters per kg of coffee cherries, 5 to 7 billion m3 of wastewater is generated yearly. There is generally a low availability of coffee husk because it is generally used for the drying process. As for the coffee pulp, because it is generally wet, its main use is in composting.

Vietnam

With 570,000 ha, coffee cultivation accounts for 3.9% of Vietnam's total cultivated area and employs 600,000 permanent workers, a figure that rises up to 800,000 workers in the harvest season (Adriana, 2009). More importantly, Vietnam has experienced a very rapid development of its coffee exploitation. Indeed, in the wake of the end of the Vietnam War in 1975, coffee was grown on only 13,000 ha (VieTrade). This steady rise is shown in Table 4 where it is noted that for the 2002/03-2006/07 period alone, Vietnam's exports rose by 56.77%. With a harvesting period that spans between October and September and an average yield of 2.2 tons/ha in 2011, Vietnam has a much higher productivity than the world average at 790 kg/ha (FAO, 2013). Of its production of 25.2m bags in 2011, Vietnam exported 24.4m bags, with imports accounting for around 370,000 bags. Despite a rise in the produced quantity, Vietnam's Robusta remains below average with a lack of standards. In comparison to Colombia's price of Arabica at 131.32 $cents/lb in Dec. 2012, Vietnam's Robusta coffee was traded at 83.72 $cents/lb during the same period. The non-existence of quality-improving measures is explained by farmers' focus on yield and productivity instead of processing and storage. Vietnamese coffee is mainly processed by the dry method, a characteristic largely explained by the fact that more than 70% of coffee plants belong to small farmers that do not have the technology and funds to process it otherwise. This implies that most of the process phases are done directly by the farmers at their producing units that integrate several stages of the coffee chain. Vietnam has around 100 processing plants, with capacities ranging from 5,000 to 60,000 tons, producing a final product of around 1m tons. Also, Vietnam has 16 corporations and more than 10,000 smallholdings that specialize in roasting and grinding (Adriana, 2009). The coffee industry is made up of both private and state-owned Enterprises (SOEs), with different levels of infrastructure and equipment, which creates a competitive environment but also issues in coffee production output. A recent series of new environmental laws require the wastewater generated from the wet method to be treated, therefore introducing a barrier to those willing to produce a higher coffee quality. The processing is still done by rudimentary machinery, with modernization failing to enter the coffee sector because of a hard-to-follow development of production. RECP measures therefore should concentrate on the lowest level of the production chain. Vietnam's low-priced and government-subsidized electricity enables most coffee mills to run on grid electricity. However on the downside, 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. The largest part of solid waste in the coffee industry consists of pulp that accounts for around 40-45% of the total 500,000 tons of waste generated yearly (VCPC, 2013). With unmatched growth among coffee-producing countries, Vietnam is the ideal candidate for a steady implementation of RECP, notably because it could enable growers to rely less on government-regulated energy supply. However, still being at an early stage of modern industrialization in the coffee sector, Vietnam has other priorities, notably in terms of quality and export prices.

2.2.2 Coffee market actors

Colombia

Historically, Colombia's coffee output has been divided equally in two, with one half sold by cooperatives, and the other half sold by other retailers/exporters. Established in 1927, the National Federation of Coffee Growers processes and trades coffee both within Colombia and abroad. It is the principle representative of Colombian coffee with a total number of members exceeding 500,000, mostly farmers. With access to all Colombian districts, it reaches small coffee growers through the local cooperatives. It also serves as a provider of social programs, loans, advice on new technology, education and incentives, in the aim of improving coffee growers' conditions of life and coffee quality. Almacafé functions as the National Federation of Coffee Growers' logistical operator and plays a key role in the post-harvest commercialization process both domestically and externally. It manages a national network of various warehouses that collect, store, process, inspect and ship around 30-35% of Colombia's total coffee production. More importantly, it serves as the implementation organ of the 'Sustainability that Matters' program and the 'Purchase Guarantee' scheme to allow small farmers and resellers, who usually have no leverage for negotiation, to participate in the market. A potential implementation of RECP should be done through close cooperation with these entities.

Peru

Several cooperatives (Cooperativa Agraria Chirinos Cafetalera Prosperity, Agricultural Cooperative Service Cafetalera, Green Gold, etc.) are active in various domains. They offer training in coffee processing, protect their members, and increase their members' profits. However, a significant problem in Peru's coffee trade is the intervention of several intermediaries resulting in high transaction costs that in turn generate inefficiencies along the coffee chain. A widespread practice is the collection by sellers and coffee merchants of small quantities of selected beans at different farming and processing units, which results in a distortion of the coffee's quality and purity. The main exporter of Peruvian coffee in 2012 was Perales Huancaruna SAC, with $12m in exports, representing around 6% of total coffee exports. All in all, the ten biggest exporters account for around 62% of Peru's total exports, equivalent of $63m (Ministerio de Agricultura y Riego, 2013).

Vietnam

While the 4C Association in Vietnam regroups around 275 members to enhance the position of coffee producers on the international market and provide them with better leverage, their position still varies depending on their status. Indeed, while SOEs traditionally have had relatively easy access to credit and funding, notably from state-owned commercial banks (Tanev, 2003), it is not necessarily the case for smaller producers.

2.3 Technical and Financial support to RECP

Colombia

Little information is available on government priorities and the regulatory environment for coffee production. However, in the wake of the 2008 financial crisis, the Coffee Policy Agreement (2008-2011) was approved by the National Committee of Coffee Growers and had the support of Mr. Alvaro Uribe. It was aimed at helping the coffee industry overcome difficulties by granting economic aid worth COP$1.4 trillion (US$730m), twice the sum provided by the previous Coffee Policy Agreement (2002-2007). Of the three countries compared, the Colombian National Bank has the lowest general interest rate at 3.25%, as of July 4, 2013. Also, the government introduced a legal provision to stabilize income called the 'Price Protection Contract' which guarantees a fixed price of COP$474'000 (US$200) per 125kg bag to growers, although some producers mentioned that this is not sufficient to cover production costs which can amount up to COP$600.000 per 125kg (CNPML, 2013). Finally, with these various policies, the general priorities remain production and recovery from the effect of La Niña and the continued threat posed by coffee rust. The aim is to avoid consequent shortages but mostly to avoid deterioration of coffee quality, a tenet of Colombian coffee.

Peru

The main government priorities focus on the optimization of coffee exports with added value, the improvement of processing and drying technologies and the reduction of intermediates to improve bargaining power from small producers. Also, a secondary aim of these policies would be the enhancement of industrially finished coffee products such as roasted, ground and instant coffee. Therefore, with the conjugated effects of coffee rust and the government's will to increase and optimize production, the priority is not on the implementation of RECP. Financially, despite quite a low indicator of interest rate (4.25%) determined by Peru's Central Bank, access to credit is impeded by several rules. Indeed, one of them is the necessity for a farmer to own the proof of land holding. The engagement of several entities could prove useful for RECP for the financing of its projects: Agrobanco, a bank that concentrates on the financing of agriculture; AgroRural, a program for the agro-rural development of production and Agroideas, an organization that fosters partnerships and implemenrs environmentally sustainable agricultural technologies for small and medium-sized producers throughout Peru. At a national level, such programs could not only have a great impact on the everyday life of producers, but also on the competitiveness and quality of Peruvian coffee.

Vietnam

In Vietnam, there is widespread concern that privately owned processing companies are not reliable and therefore are not offered financial support. According to Giovannucci et al. (2004), the state-owned Vietnamese Bank of Agriculture and Rural Development (VBARD) holds around 75% of the credit market for coffee growers. While Giovannucci et al. (2004) affirm that financial solutions might exist for most actors in the coffee chain, there are severe bureaucratic limitations and a persistent inability to provide the same solutions to everyone. All in all, this reflects a problem in bureaucracy with clear cleavages in the way the bureaucratic system treats private and state firms. Also, this internal issue might be reflected in the country's interest rate, the high level of which (9%, as of July 2013) is much higher than in the two other countries analyzed in this report.

The Ministry of Agriculture and Rural Development has approved a plan to increase the coffee sector's competitive capacity by 2015, with long-term results planned for 2020. The plan includes investments reaching nearly VND33 trillion (around $1.8 billion) and aims to ensure that all Vietnamese coffee products respect international quality standards. More ambitiously, it envisages allowing producers to trade on an equal footing in the international market. More precisely, investments will be poured into the building of reservoirs and canal systems to ensure that 75% of the coffee growing areas will be irrigated by 2015, and 100% by 2020 (Adriana, 2009).

2.4 Institutional and policy framework assessment

Colombia

Because Colombia has a strong reputation on the market and therefore only needs to concentrate on efforts in the production process, the implementation of RECP could provide invaluable tools to improve these first steps of the coffee chain, but first, the government feels it needs to assist in the recovery of production before starting to introduce new technologies.

Peru

In terms of regulation, a few laws with the aim of improving the environment and the production have been passed in recent years. Among them, the General Environmental Law n° 28611 establishes guidelines and policies regarding the use of sustainable resources and promotes their conservation. Notably, item 3 shows the sustainability of natural resources. The Supreme Decree n°009-2009-MINAM establishes and defines measures of eco-efficiency for the public sector. The Supreme Decree n°003-2008-MINAM; cat.4: on the conservation of the aquatic environment, cat.3: on the irrigation of vegetables and animal drinking water. The Standard classifies coffee in degrees, moisture, particle size, health, taste and also defines the altitude at which the coffee is grown (above/under 1,200m) and provides guidelines on storage and transportation. With the intertwined influence of cooperatives and the need to overcome natural difficulties in coffee production, the implementation of RECP might appear as a subsidiary possibility but nonetheless with great effects on the coffee sector. Also, the topological features of Peru necessitate the implementation of on-farm facilities and installations. This is explained by the fact that a centralized implementation would induce too high transportation costs.

Vietnam

In 2006, Vietnam issued the TCVN 4193:2005 quality standard for its coffee. Despite this effort to enhance coffee quality, the scheme is not compulsory and only around 10% of coffee exporters adhere to it, accounting for around 1-2% of total exports (Adriana, 2009). It appears evident that most developments and concerns focus on the producing sector, therefore neglecting two aspects of the sector's future: the environmental and social implications of sectoral changes (Giovannucci D. L., 2004).

All these characteristics of Vietnam's coffee sector show how unregulated the production of coffee is, with notable differences in treatment depending on the coffee producer's status. In order to help smaller independent producers, the implementation of RECP could have a great effect on their production, since it would enable them to have greater autonomy from the state. Indeed, it could provide these growers with the necessary tools and technology to produce better coffee and avoid high reliance on the government in terms of energy supply and exports.

Table 6 : Main characteristics of the coffee sector in the selected countries

Coffee production	**Colombia**	**Peru**	**Vietnam**
Type of coffee	Arabica	Arabica	Robusta (90%) Arabica (10%)
Share in cultivated area	20%	12%	3.9%
Employment	2.2m	750'000	600,000 (800,000 in harvest season)
Total production (m bags of 60kg, 2011)	7.8	5.2	25.2
Yield (kg per ha, 2011)	633	900	2200
Harvest period	1 April – 30 June 1 Sept. – 30 Dec.	1 April – 31 March	1 Oct. – 30 Sept.
ICO composite price (Dec. 2012, in $cents/lb)	131.32	83.72	
Exports (m bags, 2011)	7.7	5.1	24.4
Imports (bags)	700'000	N/A	300,000
Competitiveness index (WEF GCI)	69th	61st	75th

Part 3. Cleaner Production potentials and opportunities

The first step was to select the companies that were eligible for a full RECP audit. This selection was done on the base of 6 selection criteria's: accessibility, motivation, size, replicability, CP potential and data availability. Full RECP audits were then performed in the selected companies. Resource consumption indicators were took into account during the audits (see 3.2). Following the audits, specific RECP recommendations were done to each company (see 3.3).

3.1 Selected coffee processing companies in the different countries

3.1.1 Specific features of companies

A final list of 13 companies was selected from an initial list of 22 visited companies. The evaluation process[2] shows that more than half of the visited companies (13 exactly) are small to medium size companies that do not export. 8 coffee processors are medium size exporting companies, and only 2 are large. In addition, except for Colombia, the companies are often located in remote areas, which implies logistic and transport limitations

Pre-selected processing farms in **Peru** are medium sized companies that produce high quality coffee and export a significant amount of their production. As they are often located in mountain areas, important travel time is required to access the farms. Resource and energy intensity of the visited farms present interesting improvement opportunities, though the financial capacities of the farms are not always sufficient to support the implementation of CP technologies.

Pre-selected processing farms in **Colombia** are predominantly small size, with limited human resources and financial capacity to carry out RECP activities. However, the overall rating shows that resource and energy intensity can be improved.

In **Vietnam** processing companies are located in the south of the country. 6 of the 10 visited companies are small to medium sized and do not export their production. This often implies a reduced capacity to finance CP measures. Therefore, the 4 medium and big sized companies are favored in the selection process.

[2] The complete list of criteria including scale arguments is fully described in the annex document to the coffee sector assessment, Annex A.

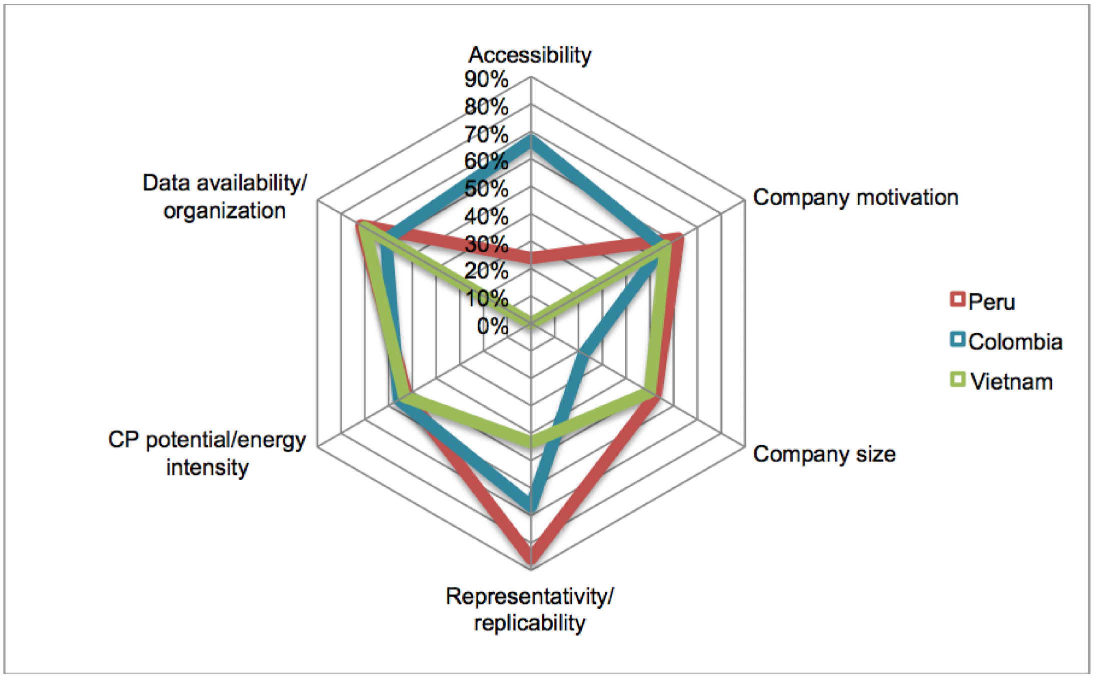

Figure 10 - Company selection with regards to selection criteria

3.1.2 Typical coffee production flow chart

The typical process flow-chart varies significantly across the 3 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 processing coffee farms** that were selected (mainly situated in Peru and Colombia). Except for coffee production in Vietnam, the global flow chart including the different processes described below does not drastically change within the selected companies. The main differences between Colombian and Peruvian farms can be summarized as follows:

1. The fermentation step is not always carried out;
2. The companies use different energy sources for the pre-drying and drying processes including electricity, fossil fuels, dried coffee organic waste or sun exposure.
3. Water management – especially for farms performing wet processing activities - significantly vary as it can be either merely consumed and directly discharged into nature, or treated before being discharged, or stored and partly reused during separation, pulping, fermentation or washing process.

An important feature characterizing almost every Latin American farm is the management and reuse of the pulp and mucilage. Composting is the most widespread technique, however vermiculture is also carried out, as well as the storage, drying and reuse of the hard shells. Composting outputs are usually used as fertilizer. Hard shells ("husk") are also valorized to produce heat for the drying process.

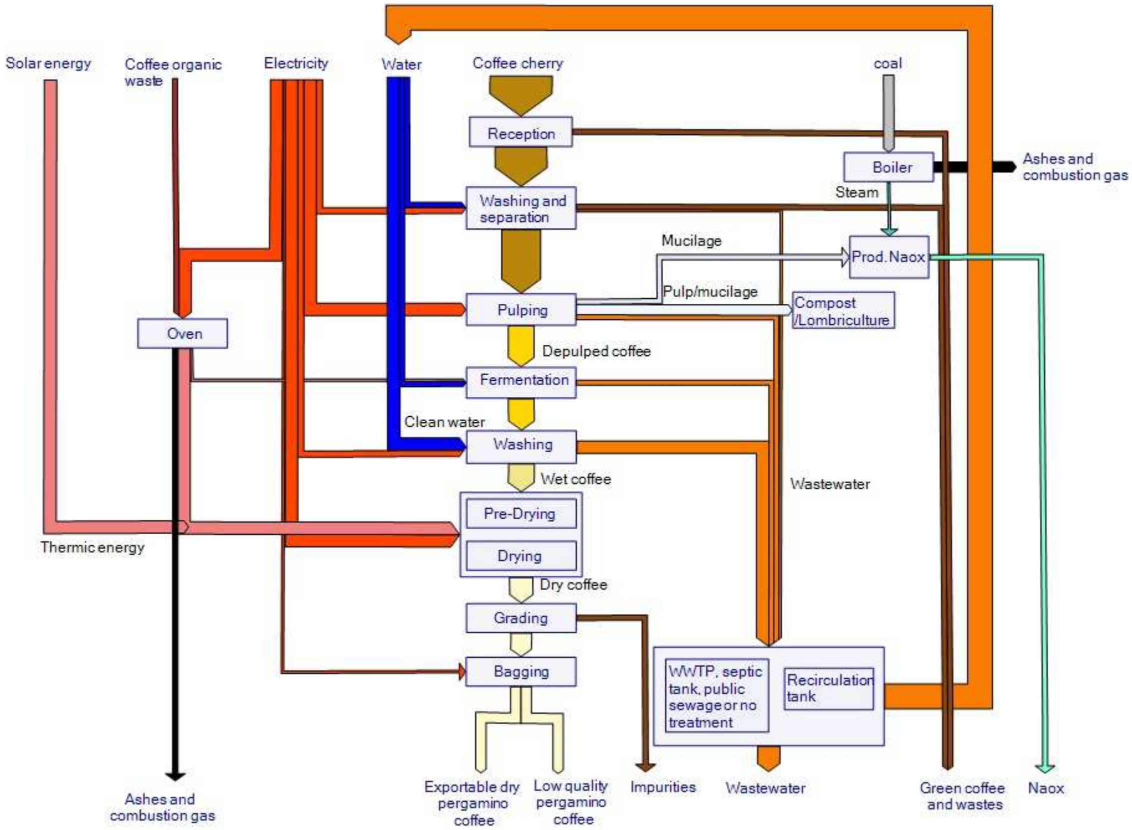

Figure 11 -– Most developed process flow-chart identified across the selected wet processing coffee farms

In Vietnam (Huy Hung, Phi Long and Simexco), the most common process identified across the selected farms is **dry processing**[3]. The main difference with the wet process in Latin American farms is that the drying step is performed either by sun drying or by using heat produced with coal or rice husks.

In the audited Vietnamese companies, coffee shells are not reused. Coal substitution by coffee shells is of interest, but thermic needs can also be provided either by the sun or with rice husks.

3.1.3 RECP potentials identified by coffee processors

According to the audited coffee processors, 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 process, screening system and internal transport** as well as for all the **motors including air compressors**. Efforts in the monitoring and maintenance, the energy efficiency and the assessment of new technologies have been carried out in some units and still represent an interesting opportunity.

[3] See the process flow chart identified across the selected dry processing in the annex document to the coffee sector assessment, annex A.

2. **Water consumption** (during the **washing process)** and **wastewater treatment and reuse** are also part of the main concerns.
3. **Dry coffee degradation and losses** caused by mechanical shocks during specific processes and internal transport is a financial burden.
4. **Waste reuse – especially of pulp, mucilage and hard shells –** as fertilizers after composting or as alternatives fuels is often already performed, but should remain a first priority opportunity, as it is financially interesting (allows savings on the costs of fuel and/or fertilizers).

3.2 Resource consumption indicators

3.2.1 Raw material and biomass consumption, and solid waste production indicators

I. <u>Raw material consumption and solid waste production</u>

As there are no available field data for these indicators in Peru, an average based on theoretical values of Cenicafé (2006, 2008) and Uribe (1977) has been used for this specific case. In theory, the weight of raw material (coffee cherry) is assumed to be 4.5 times higher than the weight of final product (coffee beans). Regarding solid waste production, it is assumed that the weight of pulp residues is 1.95 times higher than the final product weight (coffee beans). According to the Peruvian NCPC, the standard values established for Colombia are similar to the Peruvian case, and a range of only 5 % variation is assumed.

Colombian data regarding raw material consumption are partly (50%) from field survey, and partly from a theoretical standard established by Cenicafé in 2008. Solid waste productions are calculated using the raw material consumption indicator and another Cenicafé's factor, which provides the quantity of pulp per quantity of processed cherries.

Vietnamese data are entirely field based. Nonetheless, they include the values of only two from the four selected companies, because one of the companies is processing only green coffee beans and another one did not provide data. Also, the two considered companies have dry processing activities, instead of wet processing activities that is performed by all the compared companies.

It is important to interpret and compare the indicators cautiously, considering that they partly come from theoretical values, and that the size of the sample is not sufficient to be representative of the average performance in the countries.

II. <u>Biomass consumption</u>

Coffee husks are more systematically reused in Peru than in the other assessed countries. Regardless of the moisture content of the coffee before the drying process, biomass is burnt to dry the coffee. Depending on the moisture content of the input, the amount of husk needed for the drying process varies. Coffee husk consumption is therefore highly variable. It is also important to mention that the majority of Peruvian data are derived from experience, and not from a monitoring system.

By contrast, Colombian farms largely rely on coal so that their biomass consumption remains lower than Peruvian farms.

Vietnamese companies do not reuse coffee husk. It is generally used as compost or used directly for coffee roots (spreading the hard shells of coffee directly on coffee roots has a high potential against some diseases afflicting coffee trees).

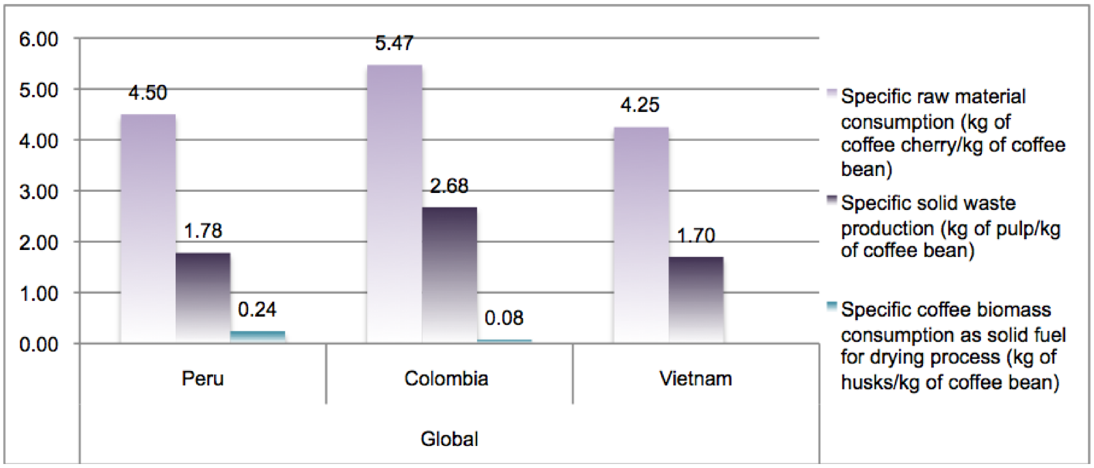

Figure 12 - Aggregated indicators for raw material consumption, solid waste production and biomass consumption

3.2.2 Fossil fuel consumption, power consumption and CO_2 emissions indicators

I. *Fossil fuel consumption*

The high Colombian CO_2 emissions result from a higher use of coal compared to Peruvian companies that exclusively depend on electricity and biomass to produce thermal energy.

Unlike other companies, the three considered Vietnamese companies carry out dry processing activities. Therefore the thermic needs are generally low. The heat is partly produced from coal but with complementary use of sun and rice husks for drying.

II. *Power consumption*

Electricity is mainly used to power the different machines used in the processing of the cherries. The specific power consumption is slightly lower in Colombia as compared to Peru, mainly because of the small size of coffee farms who sill use manual processes (e.g. manual de-pulping machines).

Vietnamese electrical needs are also low mainly because of the nature of the dry process, which doesn't go through the washing, fermentation and de-pulping steps that need motorized machines.

III. *CO_2 emissions*

The CO2 emissions of Colombian farms result from the coal consumption used for drying. The use of alternative fuel, such as coffee husks, therefore presents a promising opportunity to reduce CO_2 emissions.

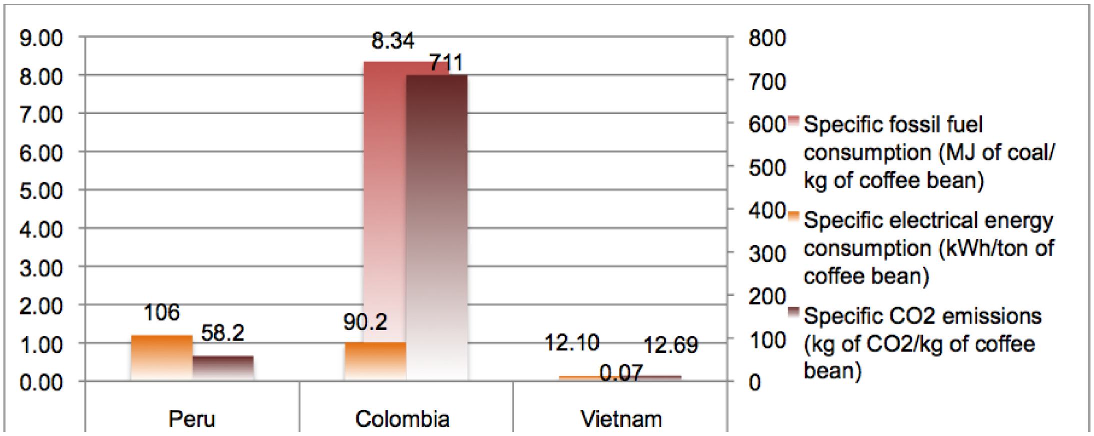

Figure 13 - Aggregated indicators for fossil fuel and power consumption and CO_2 emissions

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.

Table 7 : Classification and occurrence of RECP options

	Peru	Colombia	Vietnam
Housekeeping	**8**	**26**	**15**
Management and personnel practices	0	0	1
Process optimization	7	8	0
Efficient use of energy	7	5	**17**
Raw material substitution	0	0	0
Recovery of useful by-products, materials and energy	7	1	5
On-site recycling and reuse	2	0	0
Equipment modification	7	**28**	0
New technology	3	0	4

Several conclusions can be drawn from the figure above:

1. In all countries, companies show a specific interest regarding low cost options that can provide moderate to high benefits (housekeeping options).
2. Opportunities for improvement consist in better work practices and maintenance, but also in monitoring energy consumption to avoid unnecessary wasting.
3. Inefficient equipment is a main concern in Colombia in terms of resource consumption.
4. Aside from housekeeping options, Vietnam is focusing on inefficient energy-

consuming equipment.

In the annex document to the coffee sector assessment, Annex C, CP options are classified top-down according to the frequency of occurrence towards all the selected companies. The proposed measures are described briefly below, for each CP category.

3.3.2 Proposed CP measures

I. Housekeeping

The largest amount of CP measures identified in the coffee sector concern good housekeeping. Significant improvements can be achieved from preventive maintenance plans for either processing equipment or utilities or distribution networks such as water or compressed air. Controlling leakages, cleaning equipment and filters and systematically replacing used parts will significantly improve electric and resource efficiency.

A wide room for improvement has almost systematically been observed in the audited coffee processing plants.

II. Management and personnel practices

This category of measures is strongly related to the others, as it concerns the management practices that must be implemented in order to ensure a successful management of all RECP measures that are proposed.

For instance, the drying process in Colombia is often coal based. The handling and storage of coal can affect its quality, and should therefore be conducted with caution. The same is valid for the handling and storage of the raw material. The impact of the quality of coal and raw material on the efficiency of the industrial process is often under-estimated. The fact that only one measure of management and personnel practices was identified in the 3 countries illustrates this fact.

According to UNEP, management and personnel practices involve effective supervision, employee training, enhancing operator skills, and the provision of incentives and bonuses to motivate employees to reduce material and energy wastes and emissions.

III. Process optimization

In many cases, it was observed that existing processes could be significantly optimized in order to increase the RECP performance. This suggests that the implemented processes are adapted but not performing properly due to poor management and operations.

For instance, coffee pulp is almost always stored apart after the de-pulping operation in order to be spread out in the coffee fields as compost. Though this option makes perfectly sense, the composting process is often poorly operated so that the benefits that could be expected are not achieved.

Similar sub-standard operations have also been observed for the management of waste-water. In some cases investments have been made for tailing ponds and other pollution abatement infrastructure, but the poor operation of the system results in low efficiency of the expected result.

IV. Efficient use of energy

Measures allowing to improve the energy efficiency of coffee processing intervene at different steps and depend on the type of process that is conducted.

In Vietnam, where coffee is dry-processed, companies have a reduced thermic and power consumption per ton of coffee produced as compared to other countries. In this context, the most frequently proposed options concern controlling leakages and matching supply with demand for the compressed air systems. A better control of electrical machinery is also recommended.

In Peru and Colombia, because of the lack of energy consumption monitoring, it is difficult to collect reliable data. Is therefore difficult to assess and improve the efficiency of the drying process for instance.

V. Recovery of useful by-products and energy

The valorization of coffee pulp definitely presents one of the most interesting RECP opportunities in the sector. In Peru, a pilot pyrolysis project is testing the production of heat from pulp.

In Colombia, the production of biogas from coffee pulp is investigated, but faces problems related to the seasonality of pulp production and the time needed to produce biogas.

Other options of valorization - such as composting – are widely applied in sub-standard conditions and could be significantly improved.

Vietnam’s coffee sector presents opportunities to use coffee hard shells instead of coal.

VI. On-site recycling and reuse

This category of RECP measures mainly concerns the reuse of water for the wet process applied in Colombia and Peru.

In general, water consumption is not monitored as it is provided self-managed open sources such as bore-wells, and is considered as cost-free. Two of the audited Peruvian companies have implemented water recirculation allowing them to partly reuse the consumed water. Such systems could be easily applied to all wet processing companies.

VII. Equipment modification

In many cases, modifying or replacing existing equipment such as motors and pumps would allow for increased energy and resource efficiency.

Electrical motor efficiency is generally particularly low and could allow for significant savings after replacement by three-phase motors.

Other equipment that would allow for savings are water plumbing and processing equipment as well as cleaning equipment. Other equipment modifications concerning the transportation systems, water tanks, boilers, and pumping systems may also be considered.

VIII. New technologies

In some cases, a complete switch of technologies could be considered as the most efficient strategy for RECP. One promising alternative developed by Cenicafé is called the Becolsub process (taken from the initials of the Spanish for ecological wet coffee process with by-products handling: **B**eneficio **Ecol**ogicos **Sub**-productos). The Becolsub technology consists of pulping without water, mechanical demucilaging and mixing the by-products (fruit outer-skin and mucilage) in a screw conveyor. The technology also includes a hydromechanical device to remove floating fruits and light impurities, as well as heavy and hard objects, and a cylindrical screen to remove the fruits whose skin was not separated in the pulping machine. Scientists at Cenicafé discovered that a coffee fruit with mucilage (immature and dry fruits have no mucilage) has enough water inside for the skin and seeds to be separated in conventional pulping machines without water, that the liquid was only required as a conveying means and that pulping without water avoids 72% of the potential contamination.

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