Food and Agriculture Organization
of the United Nations

Turning rice residues into energy in combined heat and power systems in Turkey

Bioenergy and Food Security
(BEFS) case study

Purpose of the BEFS Case studies

The purpose of these case studies is to present a range of bioenergy supply chains and look at how to assess the potential within the chains based on the Bioenergy and Food Security (BEFS) Approach and BEFS Rapid Appraisal tools. The case studies have been developed for training purposes, to illustrate the BEFS approach and tools and how they are applied and to present a number of examples of bioenergy supply chains found in countries where BEFS has supported national stakeholders.

Acknowledgements

The Bioenergy and Food Security (BEFS) case studies were written by members of the BEFS Team; Luis Rincon, Ana Kojakovic, Sergio Rivero and Manas Puri, led by Irini Maltsoglou with inputs from Federica Chiozza and Vicki Romo. The graphical layout was done by Juan Luis Salazar and Christabel Clark provided editorial support. The BEFS team would also like to thank the national experts and institutions that provided input and reviewed the material used. The case studies were developed under the overall leadership of Alex Jones, Director of FAO's Climate and Environment Division (CBC), and Olivier Dubois, CBC's Energy team leader.

Our sincere appreciation goes to those working on the project activities that became the field and background work for the case studies, more specifically our thanks goes to the German Federal Ministry of Food and Agriculture, the national stakeholders in Côte d'Ivoire, Malawi, the Philippines and Turkey, the European Bank for Reconstruction and Development, and the local FAO offices in the countries.

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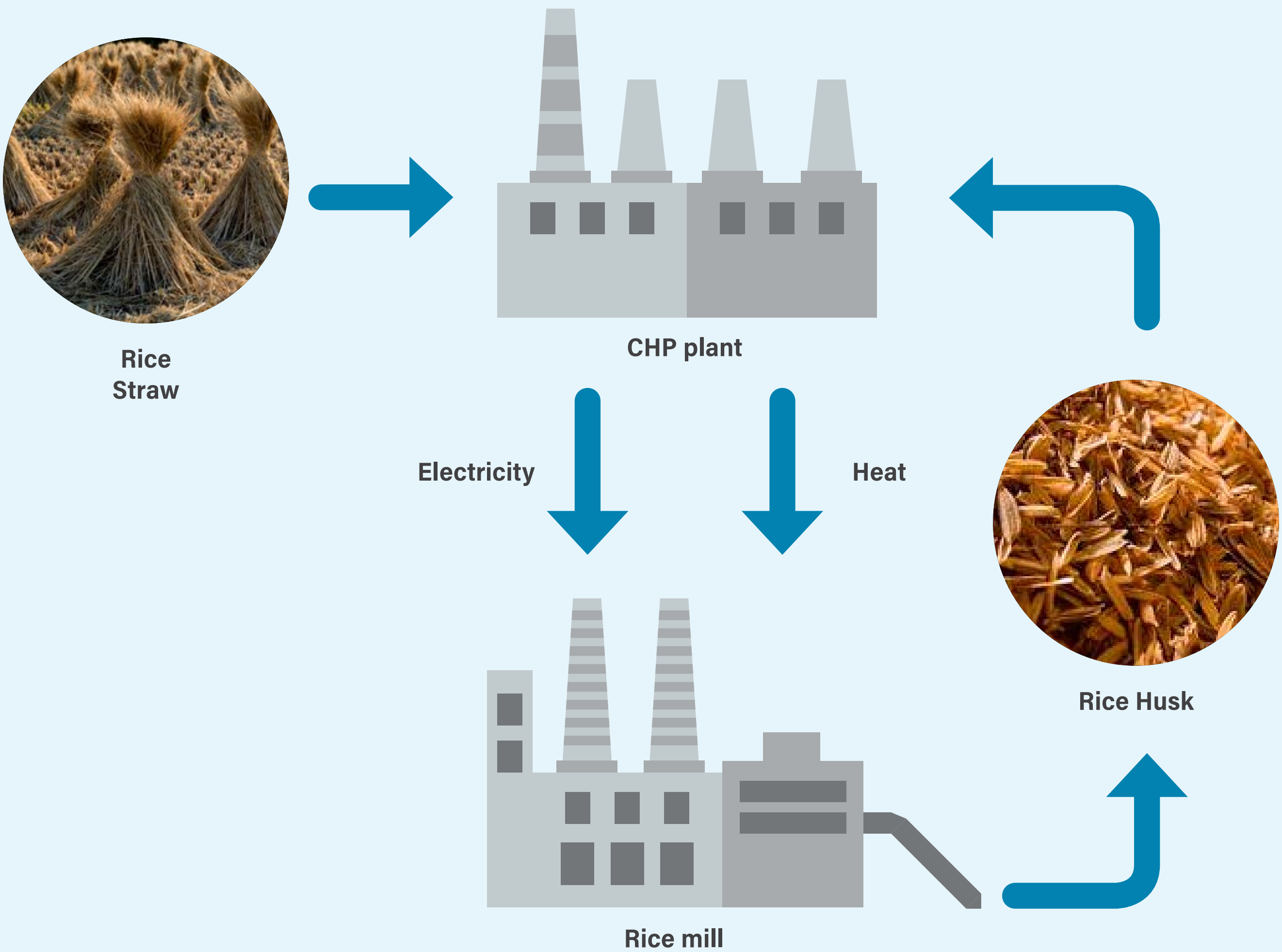
Case study focus

Turkey has a large agriculture sector and relies heavily on imported fossil fuels for most of its domestic energy consumption. As a result, the country has been trying to diversify domestic energy supply and has established several renewable energy targets by renewable energy type, e.g. biomass, solar, hydro. One of these targets is for biomass based electricity production to reach 1 000 MW by 2023. In this context, this case study presents and assesses a specific bioenergy supply chain to produce electricity in a combined heat and power system. The chain considered is that of rice residues from the rice value chain in the province of Samsun.

Key elements of the bioenergy supply chain

Feedstock	Technology	Energy end use option
Rice residues: rice husk, rice straw	**Combined heat and power systems to produce heat and electricity**	**Electricity and heat**

Bioenergy supply chain: graphical summary



Glossary

Term	Definition
Biodiesel	Biodiesel is called the mixture of esters obtained from the transesterification of triglycerides contained in oleo chemical feedstock such as vegetable oils, tallow and greases. Biodiesel can be used as substitute of diesel fuel.
Bioenergy	Bioenergy is the energy generated from the conversion of solid, liquid and gaseous products derived from biomass.
Biogas	Biogas is a mixture of gases, mainly composed by methane (50-60 percent) obtained from the anaerobic digestion of biomass. In general, most of the organic wastes can be digested (excepting lignin). Among the most common biogas substrates can be counter livestock residues, municipal solid wastes (MSW), water treatment plants sludges.
Biomass	Biomass is any organic matter, i.e. biological material, available on a renewable basis. Includes feedstock derived from animals or plants, such as wood and agricultural crops, and organic waste from municipal and industrial sources.
Biomass assessment	Biomass assessment analysis the production, availability and accessibility of biomass feedstock for energy production. The assessment considers all uses of the potential feedstock, such as their use in maintaining soil fertility, or as feed for livestock before calculating the amount of biomass available for bioenergy production. This is essential to avoid any adverse impact that bioenergy production may have on agricultural sustainability. The result of the assessment is the identification of the main types of biomass feedstock available for bioenergy production as well as their geographical distribution within a specific region or country.
Briquettes and pellets	Solid biofuel obtained by compressing biomass in order to increase density. The primary difference between briquettes and pellets is shape and size. Briquettes are generally bigger than pellets.
Charcoal	A porous black solid obtained from biomass. It is an amorphous form of carbon obtained by the thermal decomposition of wood or other organic matter in the absence of air.
CHP	CHP stands for the cogeneration of heat and power. It is an efficient method for the simultaneous generation of at least two energy forms, including heat, power, and/or cooling.
Combustion	Combustion is the most common way of converting solid biomass fuel to energy. Around 90% of the energy generated from biomass is obtained through combustion, which is traditionally used for heating and cooking. Moreover, biomass combustion technologies are actively used for electricity generation at rural and industrial scales by means of steam.
Crop residues	Plant material remaining after harvesting, including leaves, stalks, roots etc.
Ethanol	Ethanol is a short chain alcohol, which can be directly used as fuel or blended with gasoline. It can be produced through the fermentation of glucose derived from sugar-bearing plants (e.g. sugar-cane), starchy materials after hydrolysis or lignocellulosic materials (e.g. crop residues, Miscanthus) after pretreatment and hydrolysis.
Forest harvesting residues	Forest harvesting residues are parts of felled trees which are not removed from the forest. The rate of removal varies among forests and usually depends on the end product that will be made and the cost-effectiveness of removing the tree. In the case of industrial roundwood, upper logs, branches and different cut-offs are often left in the forest, while stems are removed. Sometimes, stems are debarked in the forest.
Gasification	Gasification is thermochemical process where biomass is transformed into a gas called syngas. This gas is a mixture mostly composed by hydrogen, methane, and nitrogen. Depending on processing technology, conditions and gasifying agent (i.e. air, oxygen or water). The syngas has different composition and as result different fuel qualities.

Livestock residues	Residues originating from livestock keeping. It mainly includes solid excreta of animals.
Roundwood	Wood in the rough. Wood in its natural state as felled, or otherwise harvested, with or without bark, round, split, roughly squared or other forms (e.g. roots, stumps, burls, etc.). It comprises all wood obtained from removals, i.e. the quantities removed from forests and from trees outside the forest, including wood recovered from natural, felling and logging losses during the period - calendar year or forest year.
Sawnwood	Sawnwood, unplanned, planed, grooved, tongued, etc., sawn lengthwise, or produced by a profile-chipping process (e.g. planks, beams, joists, boards, rafters, scantlings, laths, boxboards, "lumber", sleepers, etc.) and planed wood which may also be finger jointed, tongued or grooved, chamfered, rabbeted, V-jointed, beaded, etc. Wood flooring is excluded.
Techno-economic assessment	In the bioenergy context, Techno-economic (TE) assessment facilitates a data-driven decision making about the performance of a bioenergy value chain, in a given context. This methodology is based on understanding the technical (e.g., technology feasibility, biomass supplying) and economic (e.g., production costs, profitability, capital investments) features of these value chains. Depending on the context and objectives, TE assessments can be extended to include socio-economic and environmental aspects.
Wood processing residues	These residues include sawdust, slabs and chips generated as residues during the wood processing. The amount of residues generated in a sawmill depends on the type of technology used and its efficiency. Often, these residues are not fully utilized due to the lack of demand in the immediate vicinity of the processing plant.
Woodfuel	Woodfuels arise from multiple sources including forests, other wooded land and trees outside forests, co-products from wood processing, post-consumer recovered wood and processed wood-based fuels.

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Introduction and policy background

Turkey depends heavily on imported fossil fuels to meet domestic energy needs and as a result intends to expand its renewable energy production capacity to reduce its reliance on imported fossil fuels. In the National Renewable Energy Action Plan of the Ministry of Energy and Natural Resources, the Government sets out specific targets for renewable energy by renewable energy type. These include solar, wind, hydro and some biomass (NREAP, 2014)

The targets are wide-ranging and include sectoral targets spanning from renewable electricity production to energy production for heating and cooling purposes. By 2023, the government envisages that 20 percent of its energy will be coming from renewable sources, which includes the establishment of 1000 MW of capacity from biomass. In addition, Turkey is a large producer of agricultural products, which generate considerable amounts of agricultural residues. Given this context, a BEFS Assessment was undertaken to define how much renewable energy could be produced from unused agricultural residues.

The BEFS Assessment covered a comprehensive assessment of the availability of crop and livestock residues for electricity production as well as for heating and cooking, at provincial level. The energy

BOX

Bioenergy and food security (BEFS) approach

The Bioenergy and Food Security (BEFS) Approach has been developed by FAO to support countries to develop evidence based sustainable bioenergy policies. The approach supports countries in understanding the linkages between food security, agriculture and energy, and building sustainable bioenergy policies and strategies that foster both food and energy security and contribute to agricultural and rural development. A core element of the BEFS Approach is the BEFS sustainable bioenergy assessment component. The assessment covers the whole bioenergy pathway starting from feedstock availability assessment to analysis of energy end use options. The first step in the assessment component is the BEFS Rapid Appraisal (BEFS RA). The BEFS RA consists of a set of excel based tools which provide an initial indication of the sustainable bioenergy potential and of the associated trade-offs. The BEFS RA is divided into three major components: Country Status, Biomass Assessment (Natural Resources) and Energy End Use Options (Techno-economic Analysis). Each major component has one or more excel based tools linked to it.

The steps of the BEFS RA analysis:

Step 1: Country Status
This step collects information on the country status and defines the context, needs and constraints in the key sectors such as agriculture, food security, energy and the environment.

Step 2: Natural Resources: Biomass Potential Assessment
The biomass assessment estimates feedstock availability, considering competing uses and needs. The output is an initial indication of the quantities of feedstock available from crop and livestock residues, forest harvesting and wood processing residues, as well as the potential availability of crops for energy production. Profitability of different crops is also taken into consideration.

Step 3: Energy End Use Options: Techno-economic Analysis
The energy end use options module evaluates the following bioenergy options:

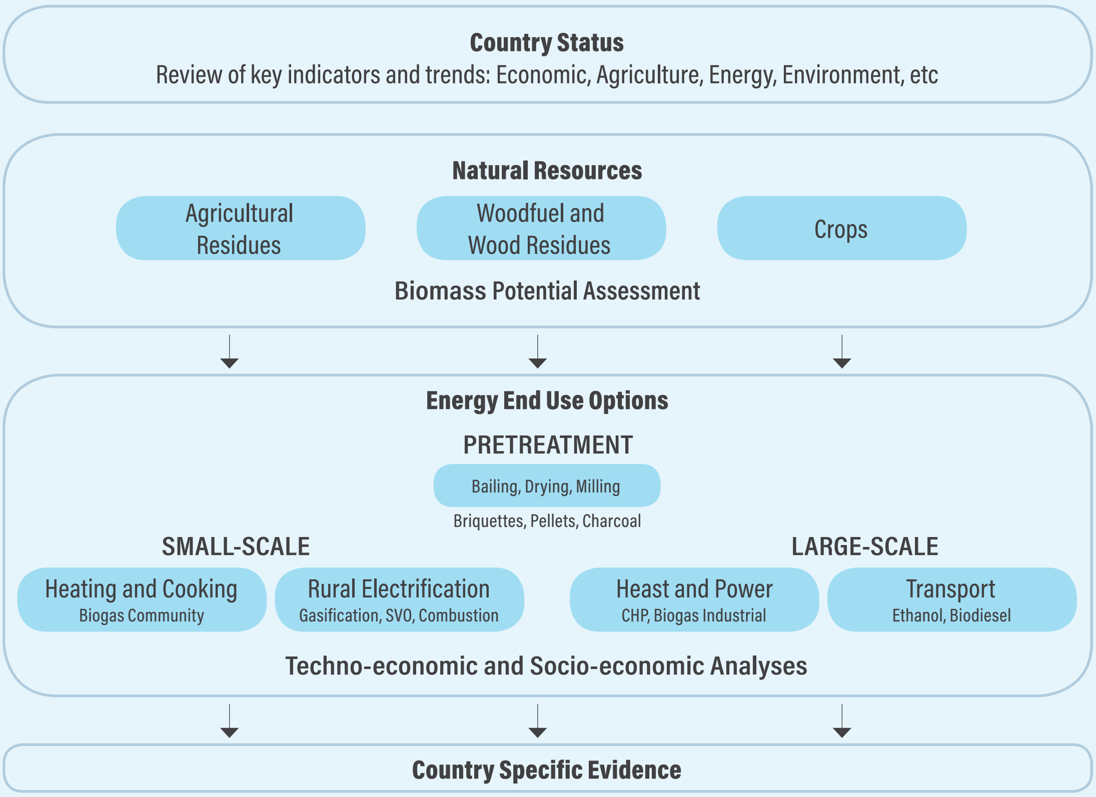
- Intermediate or final products: briquettes, pellets and charcoal;
- Heating and cooking: biogas community;
- Rural electrification: gasification, straight vegetable oil (SVO) and combustion;
- Heat and power: combined heat and power (CHP) and industrial biogas; and
- Transport: ethanol (1st Generation, 2nd Generation and Molasses) and biodiesel.

end use option technologies considered were those of Combined Heat and Power (CHP) systems, briquettes and pellets.[1]

This case study presents one specific bioenergy pathway of the set analysed, namely the production of electricity and heat in CHP systems for a rice mill to be supplied with residues from the rice value chain. Rice is produced in a number of areas of Turkey and this case-study will focus on the northern province of Samsun, one of the areas where rice is produced. The rice residues considered are rice straw and rice husk. Rice straw is generated during the actual harvesting of the residue and is a residue left in the field. Rice husk is generated during the processing of rice and is found in the mill. Rice mills in Turkey depend on coal to produce heat and grid-electricity that is then used to process rice. This case study illustrates the steps required to assess whether there is potential to generate heat and electricity from the rice residues and substitute current fossil fuel consumption in the mill. The energy generated could either substitute energy consumed within the mill or could be sold to the grid. This could in turn reduce current expenditures on energy for the mill or represent an additional income source if energy is sold to the grid.

[1] The full assessment for Turkey can be found at www.fao.org/3/a-i6480e.pdf

Each tool can be used individually but the approach advocates that output from each stage should be used as input into the following steps of the analysis. The tools are excel based and globally applicable. They can be used with limited user defined data and default values are provided. The analysis can be carried out at country or local level and tailored to address the specific needs of countries. In fact, countries can decide to assess a wide spectrum of bioenergy supply chains or, for example, to keep the analysis specific to crop residues for cooking or livestock residues for biogas generation. example.



The country context: energy and agriculture

Turkey is located at the junction of Europe, the Middle East and Asia, giving it strategic importance in international trade which, combined with a large domestic market and a stable, growing economy, brought Turkey to record a total GDP of around USD 1 122 million[2] in 2016. As a middle-to-high income country, Turkey has witnessed strong economic growth over the last decades, resulting in a stronger demand for energy from both industry and the residential sector. In terms of agriculture, Turkey is the seventh largest agricultural producer in the world (OECD, 2011) and produces significant quantities of cereals, fruit and nuts. The country is divided into seven geographical regions (Black Sea, Marmara, Aegean, Mediterranean, Central Anatolia, Eastern Anatolia and South-eastern Anatolia) and has a total population of 79 million, two thirds of which live in urban areas.[3]

Economic growth has had a significant impact on the energy sector. Between 2004 and 2014, electricity demand in Turkey almost doubled reaching 207 TWh and the demand for gas more than doubled from 22 billion m^3 to 49 billion m^3. In 2015, natural gas accounted for 31 percent, coal for 27 percent and oil for 30 percent of Turkey's total primary energy supply. Most of the energy resources used in the country are imported with only 24.8 percent of the energy supply being met by domestic production in 2015 (IEA, 2016). Rising demand for energy, high reliance on fossil fuels and limited local reserves of fossil fuels has compelled Turkey to import significant quantities of fossil fuel, which is a key challenge to the country becoming more energy secure. In fact, Turkey's electricity deficit, the proportion of imported fuel required to supply its grid, reached 6 percent of GDP by 2014, and oil and natural gas accounted for more than 90 percent of that deficit (IEEFA, 2016).

To reduce the country's reliance on imported fossil fuels, the government has set targets to use domestic sources of energy to reduce fossil fuel imports and improve energy security. These include expanding the role of renewable energy by sourcing 20 percent of total energy consumption from renewable energy sources by 2023. A specific target has been set for biomass based electricity which is to generate 1 000 MW from biomass by 2023 (Ministry of Energy and Natural Resources, 2010).

Turkey has a large agriculture sector from which considerable volumes of agricultural produce are derived every year. In turn, this produces substantial quantities of agricultural residue. These residues, which come from both crop and livestock production, could become a resource for energy production, once other uses are netted out. The number of residues that do not have other uses, could contribute to meeting the renewable energy target and increasing the share of renewable energy in its energy mix.

This case study focuses on assessing the availability of rice residues to produce electricity. Electricity generated within rice mills can be used to substitute electricity consumption within the rice mill or to produce electricity both for on-site electricity substitution and for sale to the grid.

Rice is grown on around 112 132[4] hectares (Turkstat, 2018) across Turkey with a total average output of around 894 000[5] tonnes/year (Turkstat, 2018). Over the last 10 years, the harvested area, domestic yield, as well as production volume of rice has been slowly increasing, as shown in **Figure 1**, **Figure 2** and **Figure 3**. The area harvested increased in 2012 and then slightly decreased again after that. This has been attributed to low profitability and difficulty in marketing (USDA, 2013). Over the last 10 years, the average yield of rice reached approximately 6.6 tonnes/ha and observed a steady upward trend, with some changes over time. As a result, overall the production of rice has increased from approximately 750 000 tonnes in 2008 to 900 000 tonnes in 2017, see **Figure 8**. What has also been observed is that rice consumption in Turkey is very sensitive to price fluctuations. In 2014 for instance, due to gains in the United States Dollar against the Turkish Lira, rice consumption declined and consumers switched to wheat (USDA, 2014). Nonetheless, as shown in **Figure 4**, Turkey is currently a net importer of rice (FAOSTAT, 2018).

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[2] Data for 2016, in constant 2010 USD, obtained from World Bank (https://data.worldbank.org/indicator/NY.GDP.MKTP.KD) accessed May 2018

[3] Data for 2016 obtained from World Bank (https://data.worldbank.org/indicator?tab=all) accessed May 2018

[4] Average harvested area in Turkey 2013-2017

[5] Average production quantity in Turkey 2013-2017

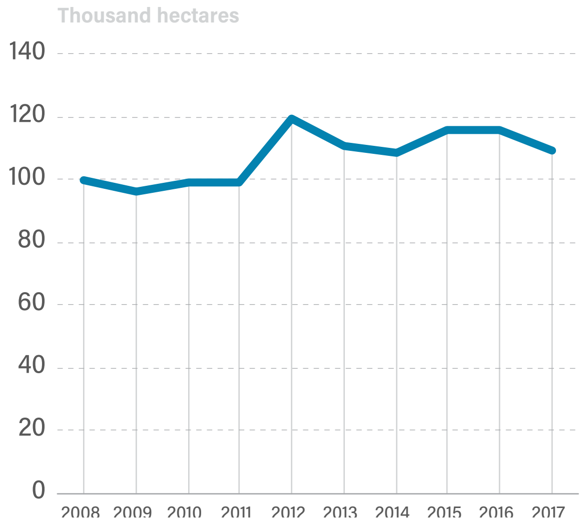
Rice is grown in around 38 out of 81 provinces in Turkey. Edirne, Samsun and Balikesir are the top 3 rice producing provinces in the country, see **Table 1**, with Samsun ranking second in the terms of rice production in Turkey. Given the considerable production of rice and the presence of a number of rice mills, Samsun was selected as the province for this case study.

TABLE 1. Top 3 rice producing provinces in Turkey

Province	Region	Rice Production (tonnes/year)
Edirne	Marmora	370 926
Samsun	Black Sea	124 352
Balikesir	Marmora	112 537

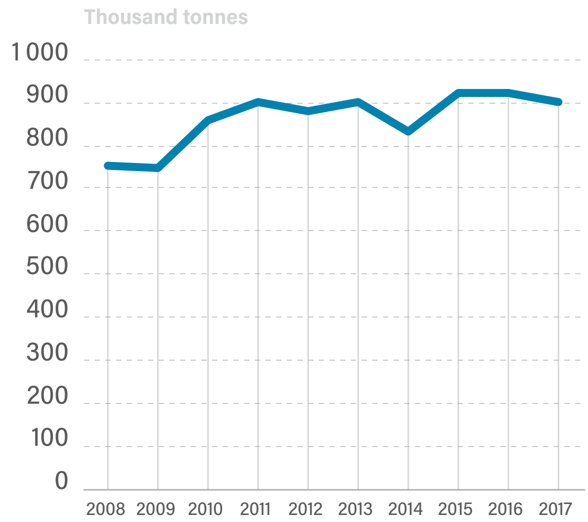
Source: *Turkish Statistical Institute, 2018*

FIGURE 1. Rice harvest area in Turkey (2007 - 2017)



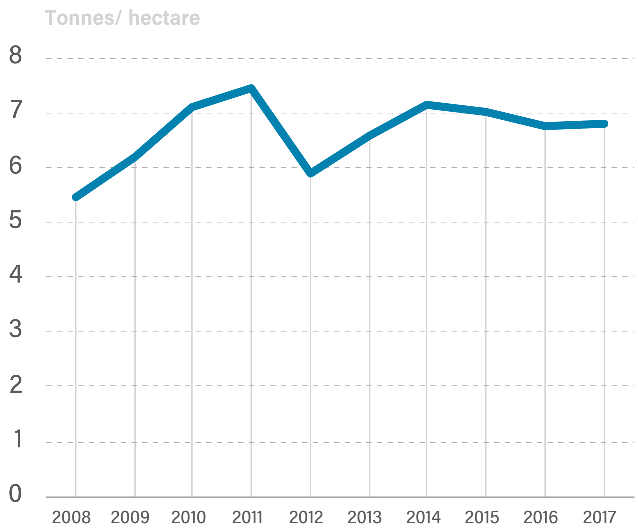
Source: *Turkish Statistical Institute, 2018*

FIGURE 2. Rice production quantity in Turkey (2007 – 2017)



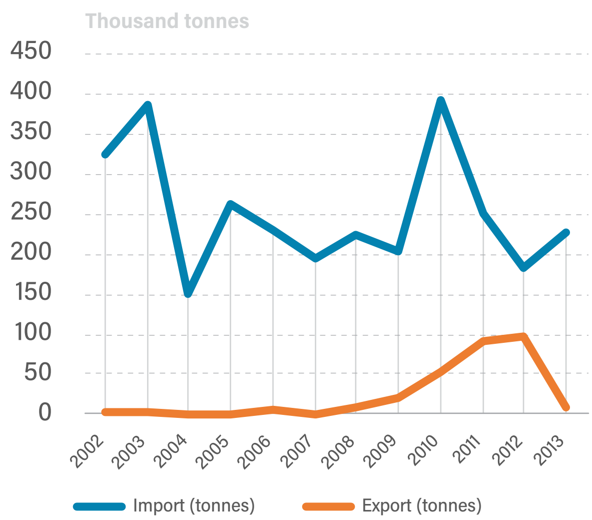
Source: *Turkish Statistical Institute, 2018*

FIGURE 3. Rice yields (national average 2008 - 2017)



Source: *Turkish Statistical Institute, 2018*

FIGURE 4. Rice imports and exports in Turkey from 2002 to 2013



Source: *FAOSTAT, 2018*

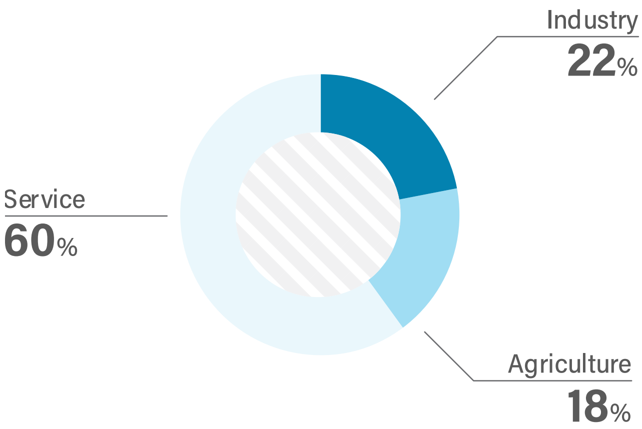
Rice production and rice mills in Samsun province

The province of Samsun province is located on the coast of Turkey's Black Sea with a total population of 1 250 000 people. The provincial capital, also named Samsun, is one of the most populated cities in Turkey and the Black Sea's largest and busiest port. The province consists of 17 districts and municipalities with an average GDP per capita of around USD 8 790, resulting in it being 38 out of Turkey's 81 provinces in terms of GDP per capita. Samsun has a total of 384 230 km² of agricultural land, of which approximately 27 percent is arable land and 4.2 percent is covered with permanent crops and agriculture contributes around 18 percent to Samsun's overall GDP, see **Figure 6**.

FIGURE 5. Map of Turkey identifying Samsun province (highlighted province)

Source: *FAO, 2016.*

FIGURE 6. GDP structure – Samsun province



Source: *Turkish Statistical Institute, 2018*

Photo by ADM Institute for the Prevention of Postharvest Loss / CC BY-NC-ND 2.0

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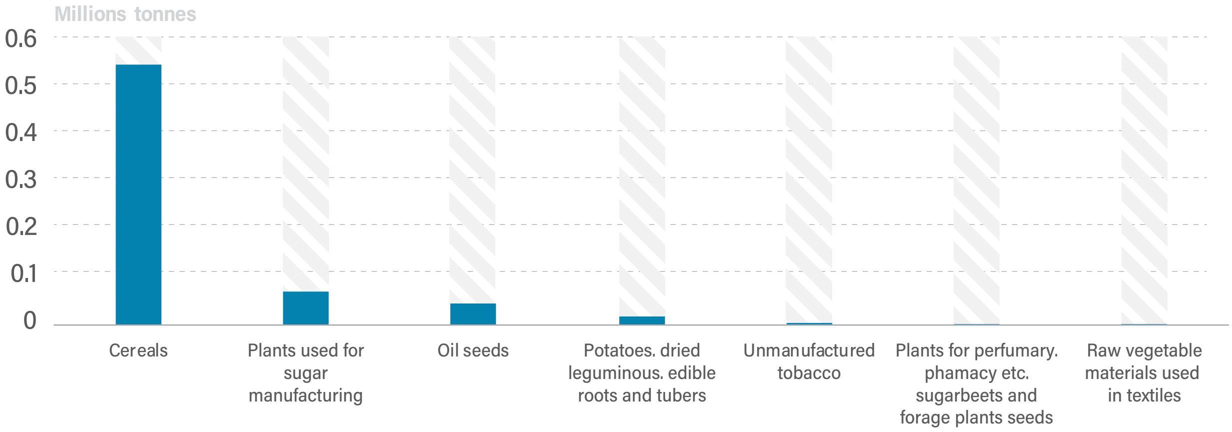
The topography of Samsun Province is dominated by three sub-regions: the coastline area, a transitional region, and the highland plateau (Ceyhan, 2010). Cereals, fruits and vegetables cover 40.9 percent, 25 percent and 8.6 percent of the cultivated land, respectively. The typical agricultural commodities grown are hazelnuts, wheat, maize, rice, oil seeds and tobacco (Mazgal and Ceyhan, 2015). Hazelnuts are mainly grown on hillslopes, while cereals, sunflowers and tobacco are grown in the plains. Hazelnut is the main agricultural export commodity from the region while cereals are mainly cultivated for domestic consumption. As shown in **Figure 7**, cereals dominate crop production by volume of production, which was around 0.5 million tonnes in 2016 (Turkish Statistical Institute, 2017).

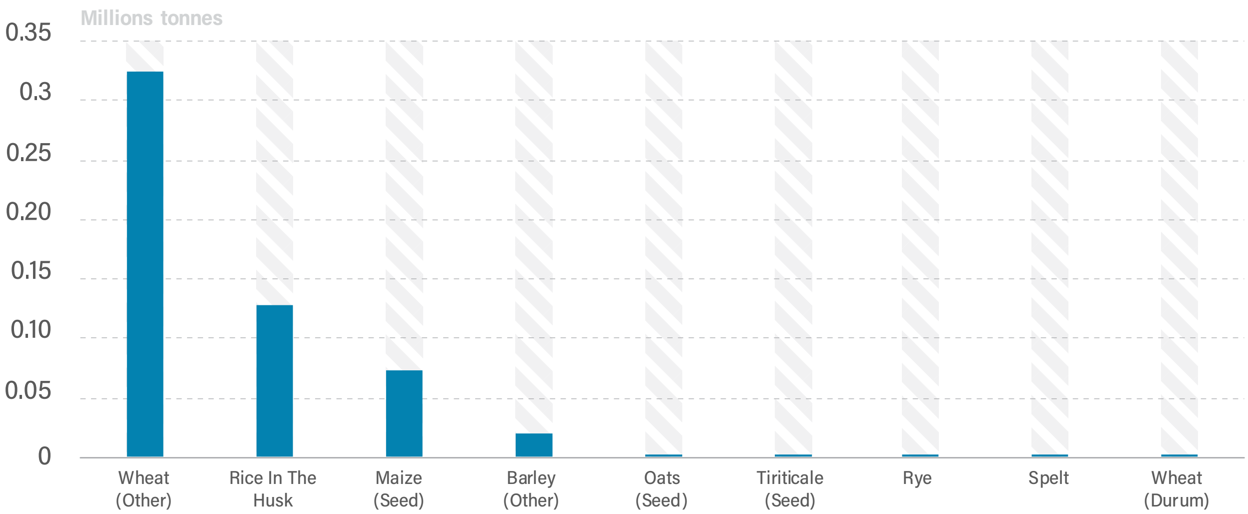
FIGURE 7. Production (tonnes) in Samsun by main crop groups



Source: *Turkish Statistical institute, 2018*

The four main cereals grown in the regions are wheat (durum and other varieties), rice, maize, and barley, see **Figure 8**.

FIGURE 8. Main cereal types

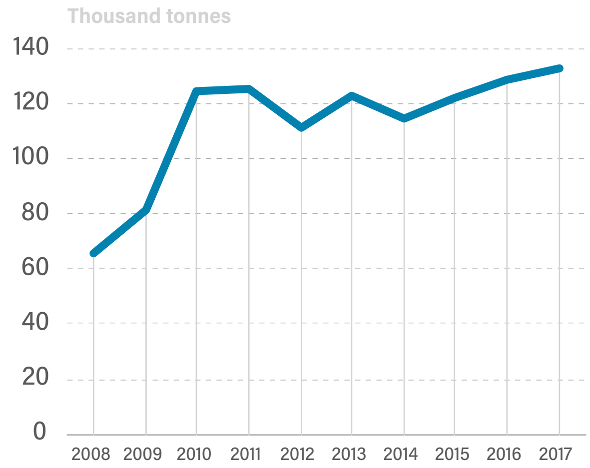


Source: *Turkish Statistical Institute, 2017*

Rice production in Samsun has been growing and doubled over the 10-year period, see **Figure 9**. On average, rice yields in Samsun have always been higher than the national average and reached an average of 8.1 tonnes/ha during the same period,[6] see **Figure 10**.

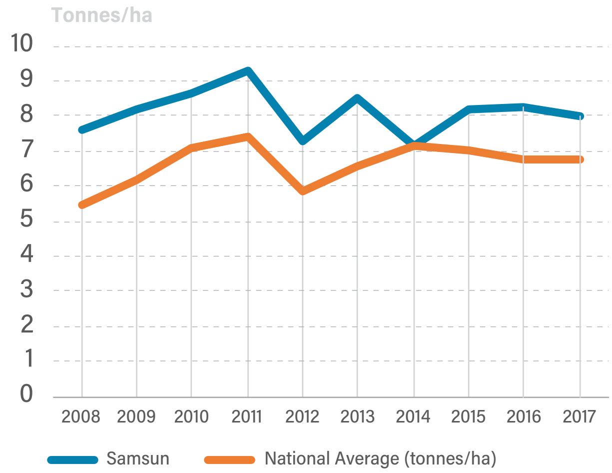
[6] Based on data from Turkstat, accessed May 2018. Average calculated for values between 2008 -2017

FIGURE 9. Rice production in Samsun (2008-2017)



Source: *Turkish Statistical Institute, 2018*

FIGURE 10. National rice yield and Samsun rice yield

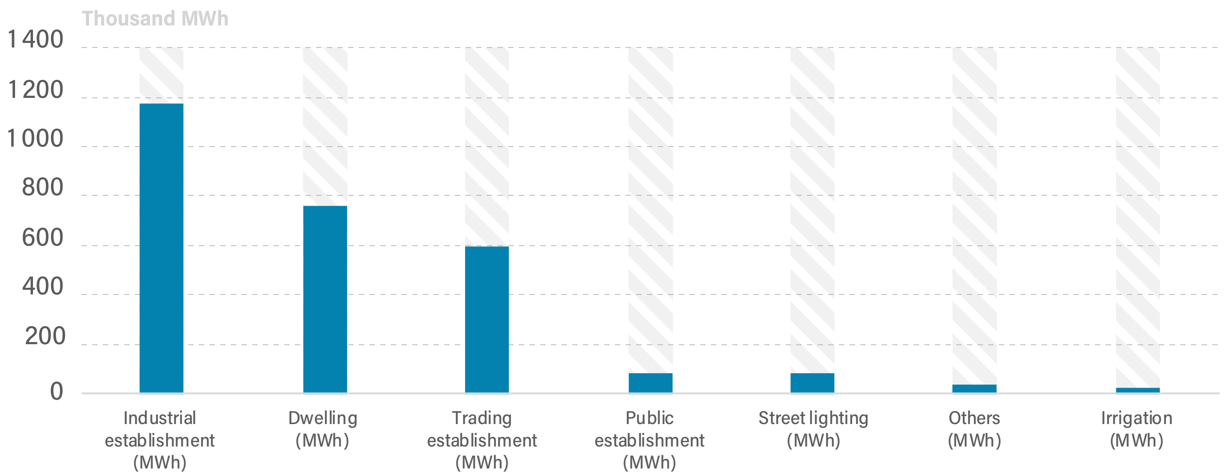


Source: *Turkish Statistical Institute, 2018*

Given the high reliance on imported fuel to produce electricity, the government has implemented a series of measures to reduce this dependency, including promoting the construction of CHP plants. By the end of 2013, the total capacity of CHP plants in Turkey reached 8 300 MW, which is equivalent to 14 percent of the total electricity installed capacity. Currently, most of the CHP plants are fuelled with natural gas plants. In addition, a national feed-in tariff scheme that promotes CHP systems that use renewable energy sources was introduced in 2012, with the aim of promoting the introduction of energy efficient and renewable energy systems.

Figure 11 shows the energy use by various sectors in Samsun. The average electricity consumption per capita in Samsun province is around 2 162 kWh (Turkish Statistical Institute, 2017), which is less than the national average of 2 577 kWh/year. Industrial establishments are the largest electricity consumer. Samsun has around 73 private agro-food factories: 23 rice, 19 flour, 17 hazelnut, 6 milk and 2 fodder processing factories, and 6 tea and legume packaging factories. All of them obtain their inputs directly from the agriculture sector (Mazgal and Ceyhan, 2015).

FIGURE 11. Electricity consumption by consumer type, Samsun



Source: *Turkish Statistical Institute, 2017*

Rice mills are a large consumer of both electricity and heat. Electricity is used to run motors, pumps, blowers, conveyors, fans, lights, etc., while heat is produced in a furnace for the rice mills' boilers and dryers. In the modern method of processing, the term milling encompasses cleaning, drying, de-husking, aspirating of husk, separating paddy and brown rice, polishing to remove the bran and grading rice and broken rice (Goyal, Jogdand and Agrawal, 2012).

Biomass assessment

Having defined the overall agricultural and energy context, the following step in the BEFS assessment is to define how much biomass could be available to produce energy. Three key elements influence the availability of residues: location of the crop residue, the crop to residue ratio and current uses of the residues.[7]

Two main types of crop residue are produced along the rice value chain; rice straw and rice husk. Rice straw is a residue generated during harvesting and left in the field. Rice husk is a residue of rice processing and is generated in the processing plant. The location where the residue is produced has significant impacts on the collection cost and the logistic set up required to mobilize the residue. Residues left in the field will need to be collected and transported to a processing plant. This will result in the residue having a collection cost attached to it. On the other hand, residues in the processing plant would in principle be readily available at zero additional cost.

The second factor that influences the calculation of how much residue is available is the Residue to Crop Ratio (RCR). The RCR is the ratio of the amount of residue generated to the amount of the main product of the crop. For example, a residue to crop ratio of 1 would mean that for each tonne of product produced, one tonne of residue is also generated. Thus, based on the annual crop production, the RCR will define the **amount of residue produced**.

Once the amount of rice residues produced is estimated, current uses of residues need to be assessed. Crop residues are used for various purposes. These include their use as feed and bedding for livestock, fuel, construction material and for soil amendment. The final quantity of residues available for bioenergy (or other purposes) is therefore calculated by subtracting the quantity used for all other purposes from the total crop residue produced. The **residue available** will result from the subtraction of the current uses of residue from the total amount of residue produced.[8]

A technical expert meeting was held in Samsun to discuss the specific rice residue parameters and the current residue uses. The experts agreed to use an RCR for rice straw of 1.00 and an RCR for rice husk of 0.25. Thus, given total rice production of 124 352 tonnes/year in Samsun,[9] the total production of rice straw is 124 352 tonnes/ year and 31 088 tonnes/year for rice husk, see **Table 2**.

TABLE 2. Crop residue RCR and crop residue production

Residue type	RCR	Residue production (Tonnes)
Rice Straw	1.00	124 352
Rice Husk	0.25	31 088

Source: *Turkstat and national experts*

In terms of uses, see **Table 3**, the national experts reported that rice straw does not have any current use in Samsun.

The straw is not used as feed for livestock or for any other local application. A few participants explained that sometimes farmers burn the straw to get rid of it. However, to avoid any negative impact on soil health in the long term, part of the residues should go back into the soil to provide nutrients and organic carbon. Local experts agreed that 10 percent of the rice straw would be left in the field for soil regeneration. Overall, this means that 90 percent of the straw can be considered available in Samsun.

[7] A full description of the steps in calculating residue availability and accessibility can be found in the agricultural residues manual of the BEFS RA agriculture residues tool www.fao.org/3/a-bp843e.pdf .

[8] To note, that once the amount of residue available is estimated, the accessibility of residues needs to be considered. The accessible residues are the amount of residue that can practically be used considering residue management, infrastructure, agricultural land, seasonality, environmental areas, etc. This is a sub-share of the residues available. This amount is site specific and dependant on data available. The case study estimates the accessible residues but assumes a conservative share. Details on the amount supplied to produce energy are included in the following sections.

[9] Given fluctuations in agricultural production, a five-year average for rice production was used. The reported figure of 124 352 tonnes/year is the average rice production in Samsun between 2013-2017 based on data from Turkstat.

Rice husk, on the other hand, is partly used as bedding for poultry and is bought by poultry farmers directly from the mill. The national stakeholders reported that 50 percent is currently used for these purposes, meaning that the other 50 percent could be considered available for purposes such as bioenergy production.

TABLE 3. Existing uses of rice straw and husk in Samsun

Crop residue	Left in the field	Animal feed and bedding	Total already used	Available for bioenergy	Crop residue available
Rice Straw	10%	0 %	10 %	90 %	111 917
Rice Husk	0%	50%	50%	50 %	15 544

Source: *Technical consultation in Samsun and Turkstat 2018*

At first glance, the amount of rice straw that could be available appears to be considerably larger than rice husk. This is a combined result of the RCR and the other current uses of the residue. However, as explained above, rice straw is spread in the field, and therefore needs to be collected, transported and pre-treated before it can be used for energy production in the mill. Furthermore, given that the residue is spread in the field, the actual amount of residue that could be accessed is not clear at this stage. For the assessment, it was assumed that only 20 percent of the straw is accessible. This is an initial conservative assumption to avoid over estimating final energy production that would need to be validated case by case. Rice husk, on the other hand is produced in the mill itself and therefore has the advantage of not having any additional costs attached to it, e.g. transport etc. This residue can be fully accessible (although other uses would still need to be checked).

Based on all the steps illustrated, the final amounts of rice residue considered available for energy production in Samsun are 22 383 tonnes/year of rice straw and 15 544 tonnes/year of rice husk. These amounts are the total amounts for the region. Individual mills would produce a part of these or source a share of the total rice straw calculated as available. These amounts provide an indication of the overall amounts that could be accessed in the region from the total rice production and rice mills.

TABLE 4. Quantity of rice straw and husk accessible for bioenergy production in Samsun

Crop residue	Quantity assumed to be accessible for bioenergy production (tonnes/year)
Rice straw	22 383
Rice husk	15 544

Source: *Technical consultation in Samsun and Turkstat 2018*

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Techno-economic assessment

The above-mentioned crop residues can be used in CHP systems to generate electricity and heat. This technology can be useful for rice mills as an option to substitute their energy needs with internally sourced energy or, if surplus energy is produced, as an additional income source.

The next step in the BEFS assessment is to define, based on the residues available, what CHP set ups can be economically viable, considering the specific context at hand. The CHP analysis needs to be carried out at mill level, thus the focus of the assessment will now move to one specific mill in the Samsun region.[10]

The amounts of residue previously calculated will represent the overall envelope of rice residues available in the region. In the specific mill considered, the national stakeholders reported that 2 000 tonnes of rice husk were produced in the mill, see **Table 5**. Given this and the previously estimated ratio between rice straw and rice husk, it is possible to deduce from the rice processed that 8 000 tonnes of straw would have been generated in the field. In addition, considering the availability shares of 50 percent for rice husk, the final amount of rice husk was 1 000 tonnes. For the case of rice straw as this residue is spread in the field, a conservative 20 percent accessibility rate was also considered and an availability share of 90 percent. Due to this, the final amounts of rice straw assumed available was 1 440 tonnes.

TABLE 5. Residues potentially available from a rice mill producing 10 000 tonnes of rice/year

Residue	RCR	Rice mill production (tonnes/year)	Total already used (%)	Residues location	Total accessible	Total available for CHP
Rice Straw	1	8 000	10%	Spread in the field	20%[11]	1 440
Rice Husk	0.25	2 000	50%	Processing plant	100%	1 000

The selection of CHP technology features, such as type and generation capacity need to be linked to the target site or facility that it will serve. In this case study the target site is a rice mill, considered as the beneficiary of the cogenerated energy. The case presented here is for a medium level rice mill from the Samsun province. The energy demand characteristics of the mill selected for the analysis and other key parameters are listed in **Table 6**.

TABLE 6. Rice mill characteristics

	Value	Unit
Paddy crushing capacity	10 000	tonnes /year
Rice husk collection cost	0	USD/tonne
Rice straw collection cost	62.6	USD/tonne
Estimated electricity demand	783 000	kWh/year
Equivalent electricity capacity demand [1]	99	kWe
Estimated heating demand	770 000	MJ/year
Equivalent heat capacity demand [1]	27	kWth
Price of electricity (from the grid) [2]	0.08	USD/kWh
Feed-in tariff [2]	0.133	USD/kWh

Source: *Values reported by the technical experts in Samsun or calculated as explained in the notes. 1 Electricity and heat capacity equivalents are calculated to allow for comparison across energy demand options. 2 Values collected in the field at the time of the analysis in 2016.*

The energy demand of the selected rice mill is 783 000 kWh/year of electricity and 770 000 MJ/year of heat. To allow for comparison across energy types, the equivalent for electricity and heat are

[10] The national experts from Samsun proposed and selected the mill to be assessed in the region.

[11] When considering the actual amounts of residues available and to be used for energy production, accessibility should also be considered for residues spread in the field. For the initial level of analysis presented here, a conservative assumption of 20 percent accessibility was considered and included in the estimate of this amount.

calculated in kW equivalent terms. Thus, the mill will require 99 kWe of electricity and 27 kWth of heat. The analysis will define if and how these amounts of energy can be generated from the CHP system and if this can be economical. Currently, the mills buy electricity from the grid and generate heat from coal bought from the market.

Overall the techno-economic analysis will define:

1. Which feedstock (rice residue) is more profitable to be used in a rice mill?
2. Should the CHP set up be for own consumption or to sell excess electricity to the grid?
3. What is the required investment and the production costs?
4. Which feedstock would reduce GHG emissions the most?

CHP systems are intended for the simultaneous production of two energy forms, namely heat and power. Thus, as a first step, it is necessary to decide the operation mode and define if the case considered requires prioritizing heat over electricity or vice versa. This will be dictated by the energy demand of the facility and the amount of residue available. The analysis covers two operation modes: thermal tracking and electricity tracking. The first option prioritizes heat production over electricity, while the second prioritizes electricity production over heat. The plant size adjusts according to the operation mode selected. In addition, CHP technology variations were considered to capture differences in technology complexity and options in terms of heat to electricity output ratios. This resulted in three technology profiles: simple, semi advanced and advanced.[12] The investment requirement will also increase with the complexity of the technology. Furthermore, two key variables that affect the potential performance and the economic feasibility of the system are also considered in the analysis, namely the energy potential of the feedstock and the collection costs.[13] For the case of the CHP analysis, the size of the system varies and will depend on the technology chosen and on the feedstock considered.

The first step in the analysis, considering the amount of residue available and the feedstock energy potential, is to run the three CHP technologies and two feedstock options in thermal tracking and then in electricity tracking mode. The results are presented in **Figure 12**. Within each chart the orange bars represent the heat generation capacity while the red bars represent the electricity generation capacity. The results are presented by feedstock type and tracking mode. The results illustrate how the different CHP technologies result in different heat to electricity generation ratios and that more energy is generated from the larger amounts of straw available.

[12] To note, the "simple" technology is not a CHP technology *per se* but is a baseline technology. This represents the generation of electricity from direct combustion of biomass in a boiler.

[13] The high ash content in rice straw might cause problems of deposits and agglomeration formation during combustion. These problems are mainly caused by the presence of silica in the chemical composition of rice straw (Miles *et al.*, 1996). Although, new boiler designs consider alternatives to reduce the effect of this problem, it is important to keep a preventive maintenance program for the boilers and reactors fired with straw.

Cogeneration technologies

Cogeneration systems are an efficient way of producing at least two forms of useful energy. The sequences of generation can be any combination of heat and power, mechanical energy and heat or even electricity and cooling. The most widespread and well-known cogeneration systems are those intended for the generation of heat and power. For this reason, cogeneration is also known as CHP (cogeneration of heat and power).

The combined production of useful energy using a single energy source, such as oil, coal, natural gas or biomass, ensures significant cost and energy savings and systems that are more efficient than single operating systems. This system is commonly used to meet the energy requirements of different industrial and commercial facilities such as rice mills, sugar mills, as well as hotels and airports.

The benefits of cogeneration include:

- ► A cost-effective method for GHG emissions reduction
- ► Reduced energy losses
- ► Improvements in energy efficiency
- ► A decrease in operating expenses
- ► Surplus electricity that can be sold as an additional source of income

However, cogeneration systems also have limitations:

- ► To be cost efficient and operationally effective, cogeneration is only suitable for sites with a simultaneous and consistent demand for the generation of two energy forms.
- ► Capital investment and installation costs can be high since cogeneration technologies are usually custom-made designs for specific sites.
- ► A cogeneration system must be selected according to the energy needs of the target plant, considering all energy requirements. Some plants use systems that produce more electricity than heating, or more heating than electricity. This feature is considered in this BEFS assessment by including three cogeneration technology variations:
  - i) Simple technology (intended for electricity production only)
  - ii) Semi-advanced technology (intended for cogeneration producing more electricity than heat)
  - iii) Advanced technology (intended for cogeneration of more heat than electricity)

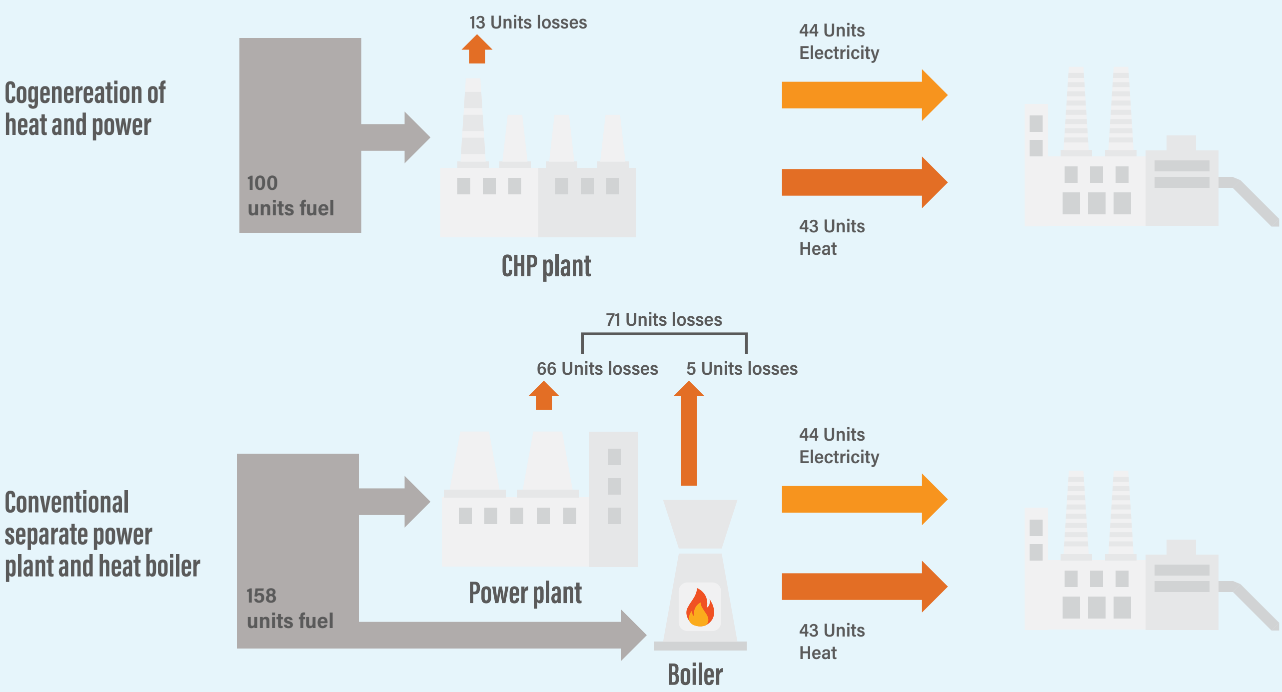
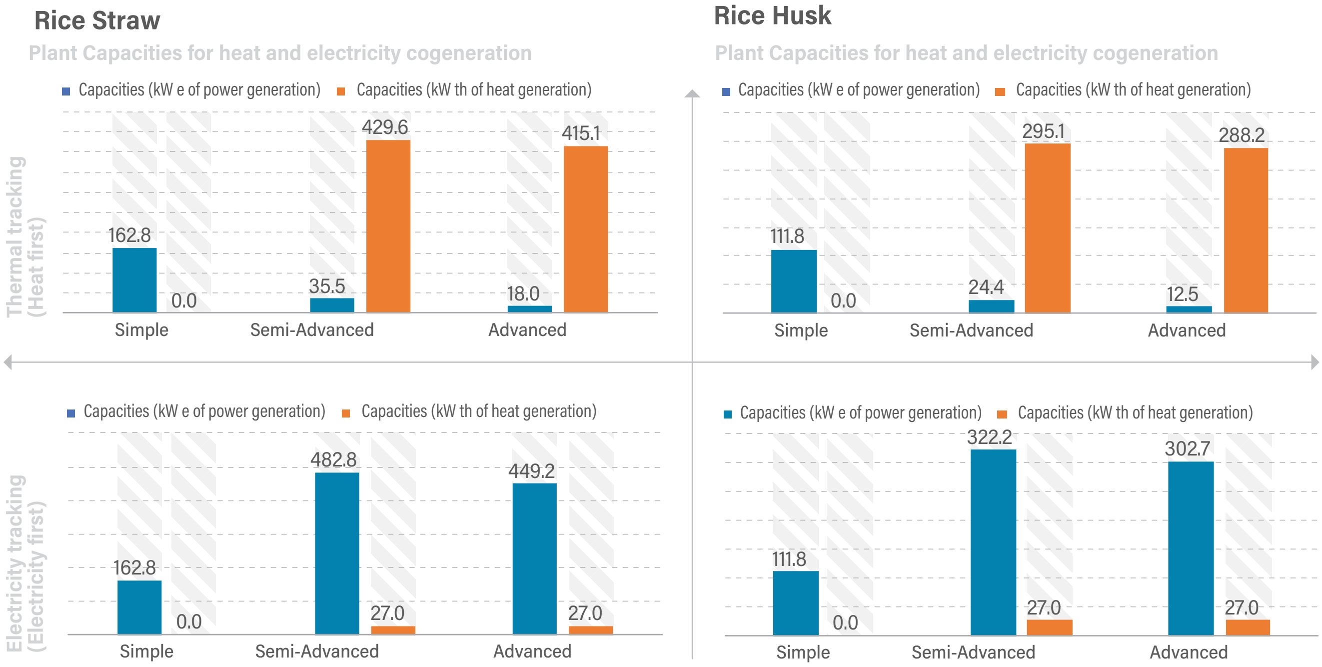


FIGURE 12. Comparison of CHP capacities for rice straw and rice husk under two operation modes



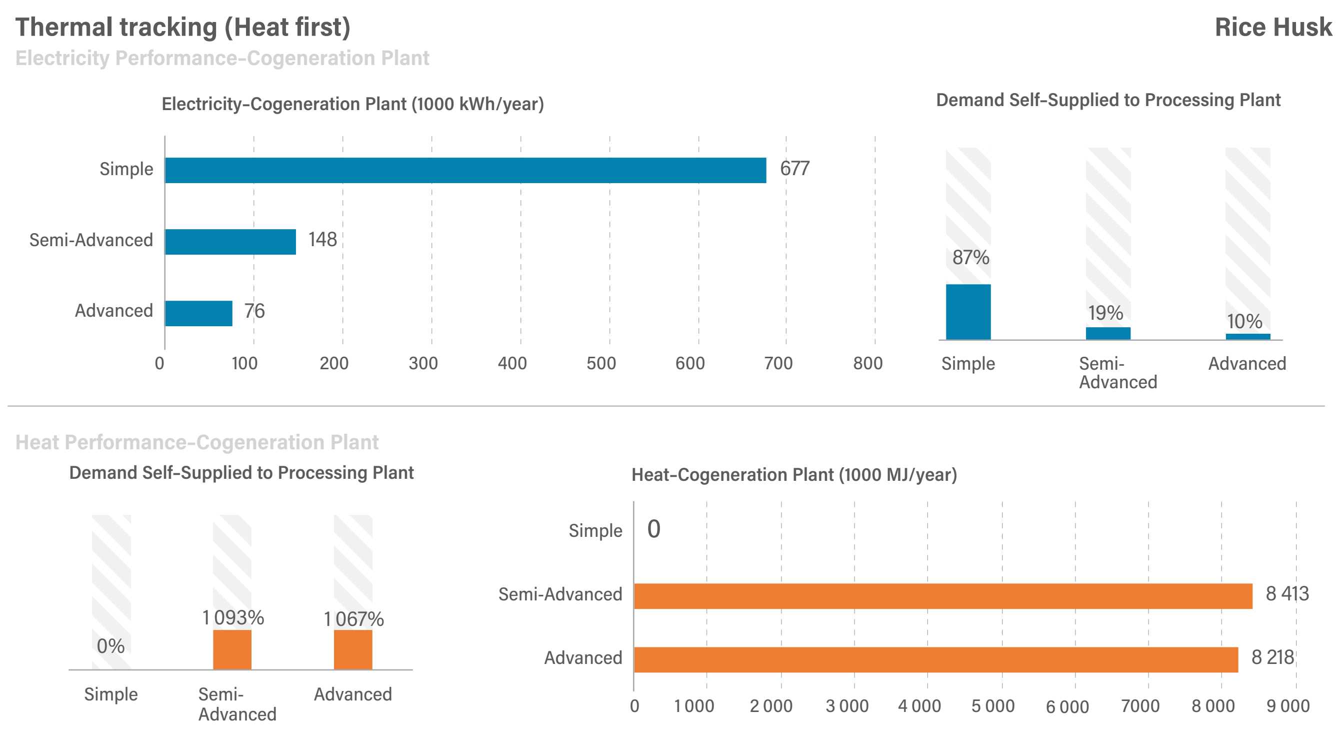
Source: *Results from BEFS RA CHP tool*

The next set of results need to be considered by feedstock. We first start from the case of rice husks. The same trends in results would apply to the case of rice straw.

The results presented in **Figure 13** illustrate the amount of heat and electricity that can be generated from rice husk under thermal tracking mode. It considers all three technology types; simple, semi-advanced and advanced. The results suggest that under thermal tracking mode, only a portion of electricity needs can be met by each technology option (19 percent by the semi-advanced technology and 10 percent by the advanced technology). If the simple technology set up were to be used, more electricity can be generated but it would still only meet 87 percent of the demand of the mill. Conversely, heat demand would be met under all technology options. Therefore, in case the selected CHP technology would be operated under the thermal tracking mode, the system would generate excess heat with a deficit of the electricity demanded. Given this, this CHP option would not be suitable for the mill energy requirements.

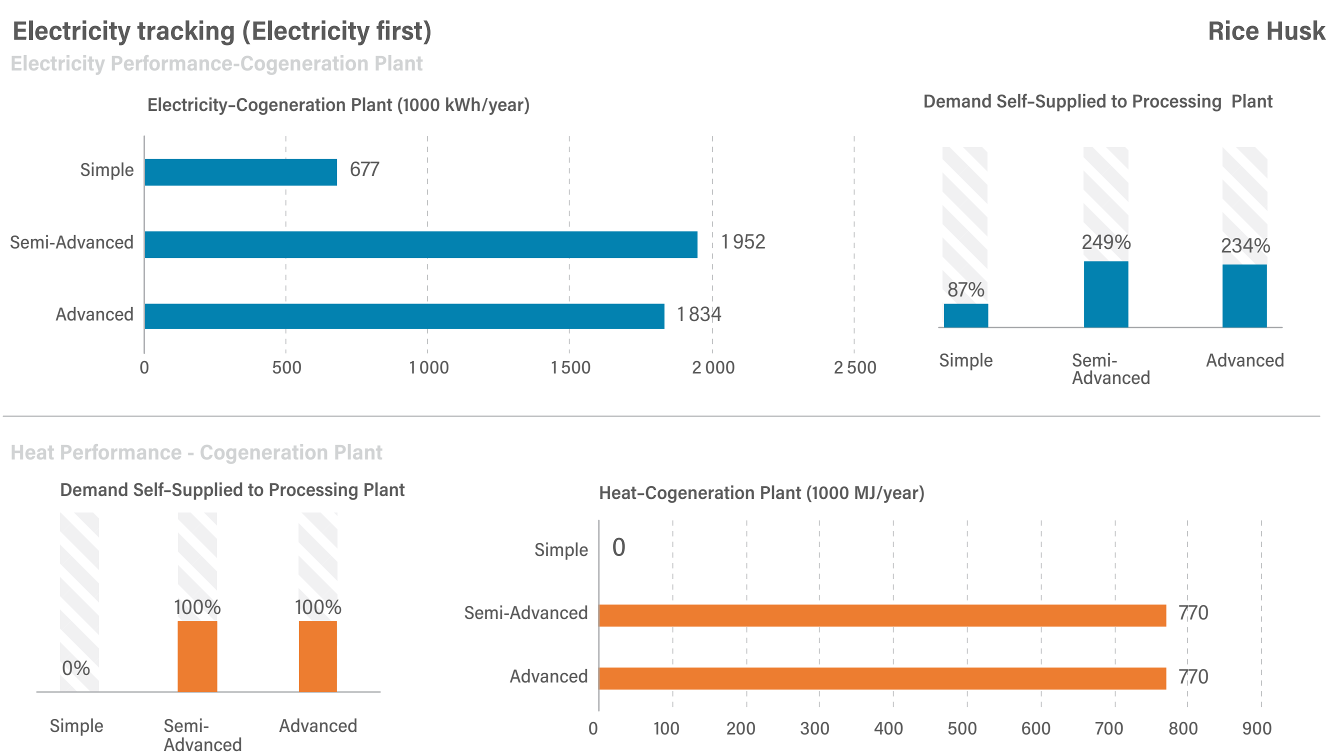
On the other hand, under the electricity tracking mode, the results show that the electricity demand of the mill could be fully met, as well as the heat demand, except for the simple technology case that does not produce heat by construction, see **Figure 14**. This result also stems from the fact that the heat demand of the rice mill is much lower compared to the electricity demand of the mill. In addition, Turkey has set up a feed-in tariff system for electricity generated from renewable energy sources, so in this case the surplus electricity could be sold to the grid. The Renewable Energy Support (YEK) Mechanism of Turkey stipulates a feed-in-tariff up to 0.133 USD/kWh for biomass-based power plant facilities locally manufactured. Consequently, given the amounts of energy produced, the electricity tracking mode would ensure that the heat and electricity demand of rice mill is met and that surplus electricity is sold to the grid. This will be further analysed in the following section. It should be noted that the same set of results would also apply to the case of rice straw.

FIGURE 13. Results for thermal tracking – Rice Husk



Source: *Results from BEFS RA CHP tool*

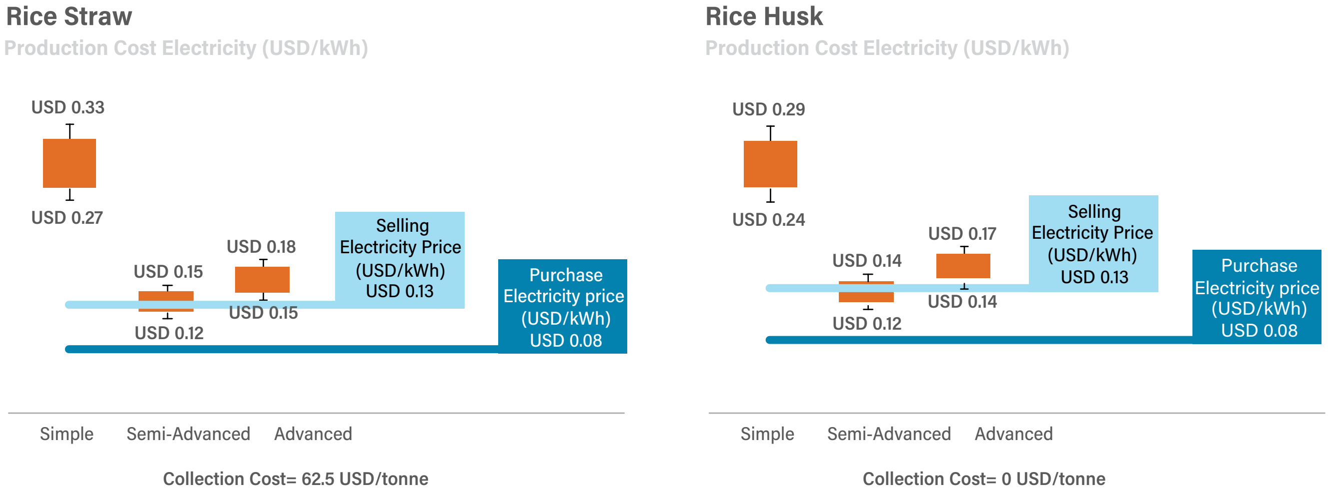
FIGURE 14. Results for electricity tracking – Rice Husk



Source: *Results from BEFS RA CHP tool*

Given this initial set of results, the electricity tracking mode option should be selected. Now the performance of two feedstock options (rice straw and husk) need to be selected and the differences in investment requirements need to be accounted for. **Figure 15** shows the comparison cost of production of electricity from rice husk and rice straw in electricity tracking mode for the three technology variations. These costs are compared with the current purchase price of electricity of 0.08 USD/kWh, and the defined feed-in tariff of 0.13 USD/kWh (see table containing the rice mill key data). In terms of collection costs, rice husk is produced in the mill itself and due to this has no collection cost attached to it and the cost to the mill is zero. On the other hand, rice straw needs to be collected and transported to the mill, thereby coming at a cost to the mill. As illustrated in the rice mill characteristics table, the estimated collection cost for rice straw is 62.5 USD/tonne based on the data collected in the field. Given differences in the collection cost of rice straw and rice husk, the unitary cost of electricity production from rice husk is lower than rice straw for all the technology types. Considering the electricity price, the feed-in-tariff and the differences in the collection costs, the results show that the unitary production costs of electricity from CHP and rice residues are higher than the price of electricity from the grid. This is also the case when considering the feed-in tariff scheme. The semi-advanced technology is the one case for which the unitary production costs are close to the feed-in tariff scheme price (for both rice husk and straw)[14], and therefore the best option.

FIGURE 15. Comparison of unitary electricity generation costs (USD/kWh)

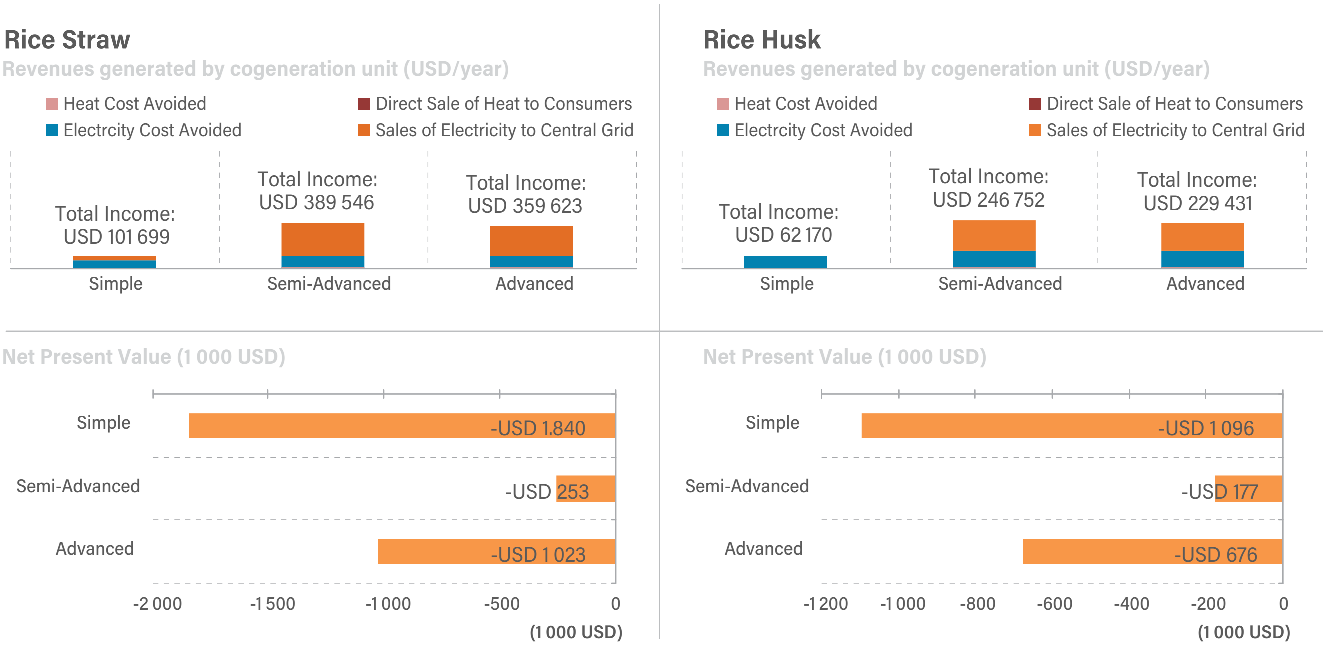


Source: *Results from BEFS RA CHP tool*

The price of feedstock, i.e. of rice husk and straw, and the feed-in tariff for electricity are the key variables that impact the overall profitability of the CHP system. The quantity of available rice straw is larger than that of rice husk and this has an impact on the overall revenues of the CHP plant as shown in **Figure 16**. However, the revenues generated are not enough to compensate for the high production costs. Consequently, the profitability of both options is negative, see **Figure 16**.

[14] Heat production cost results are not presented. The main reason is that this is a result presented where obtained under the electricity tracking mode, which optimizes the system to produce just enough heat to meet the necessities of the mill, while all the remaining available energy is used for electricity production. Therefore, electricity will be the only critical factor affecting the overall profitability and performance of the system.

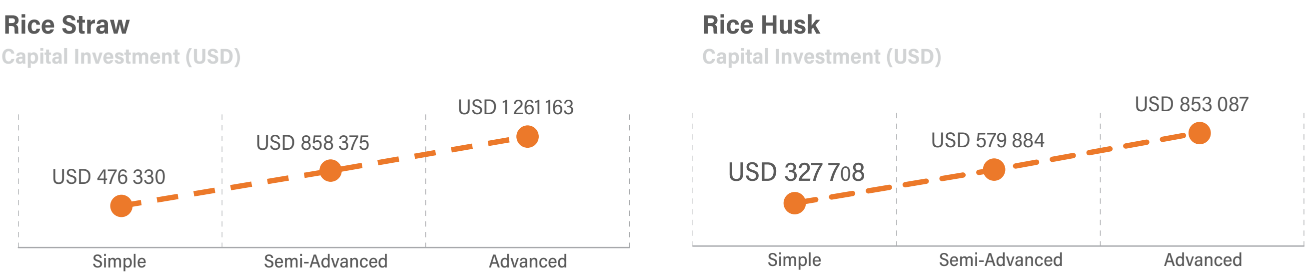
FIGURE 16. Comparison between revenues and profitability of rice straw and husk



Source: *Results from BEFS RA CHP tool*

Another factor impacting the profitability of these projects is the capital investment requirements, see **Figure 17**. As seen in **Figure 12**, a rice straw fired CHP plant using semi-advanced technology could have a capacity of 429.6 kW electricity. The investment required for this capacity is USD 858 375. Conversely, a rice husk fired plant of 295.1 kW electricity would cost USD 580 884.

FIGURE 17. Capital investments for CHP plants under electricity tracking mode



Source: *Results from BEFS RA CHP tool*

It is common in countries with policy incentives such as a feed-in tariff schemes, that the processing plants owning CHP systems adopt an operation scheme, whereby the plant continues to purchase electricity from the central grid, and sells all electricity produced from the CHP system back to the grid at the preferential feed-in tariff rate. This results in higher profits as discussed below.

Figures 18 and 19 present a comparison of revenue and profitability for rice straw and husk under two electricity selling options: 1) Self supply first and sell surplus to the central grid and 2) all electricity sold to the central grid. The obtained results show the difference between the electricity price and the feed-in tariff, allowing CHP plants to increase their revenue by 16 to 34 percent. Thus, both feedstock options using semi-advanced technology would be able to generate a considerable profit, namely USD 368 000 for rice straw and USD 361 000 for rice husk. In addition, the return on rice husk is higher than that on rice straw, USD 0.62 profit/ USD invested and USD 0.42 profit/ USD invested respectively.

FIGURE 18. Comparison of revenues and profitability of electricity end use options – Rice Husk

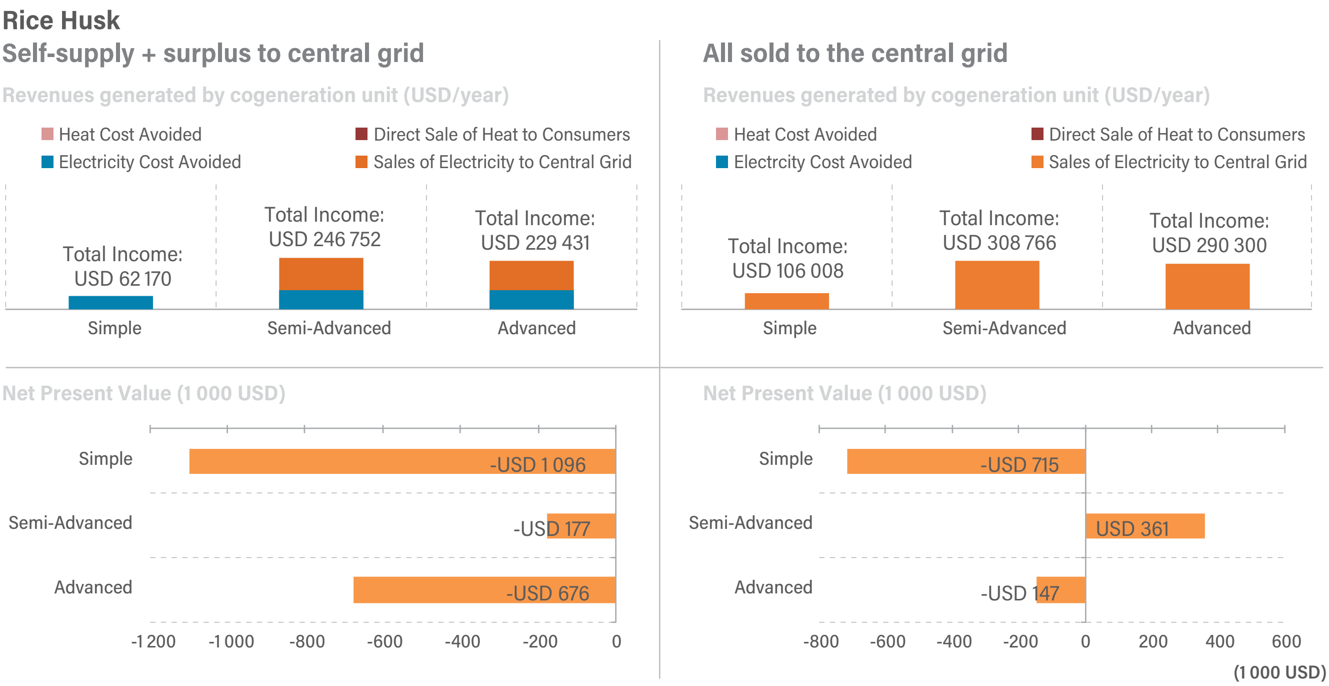
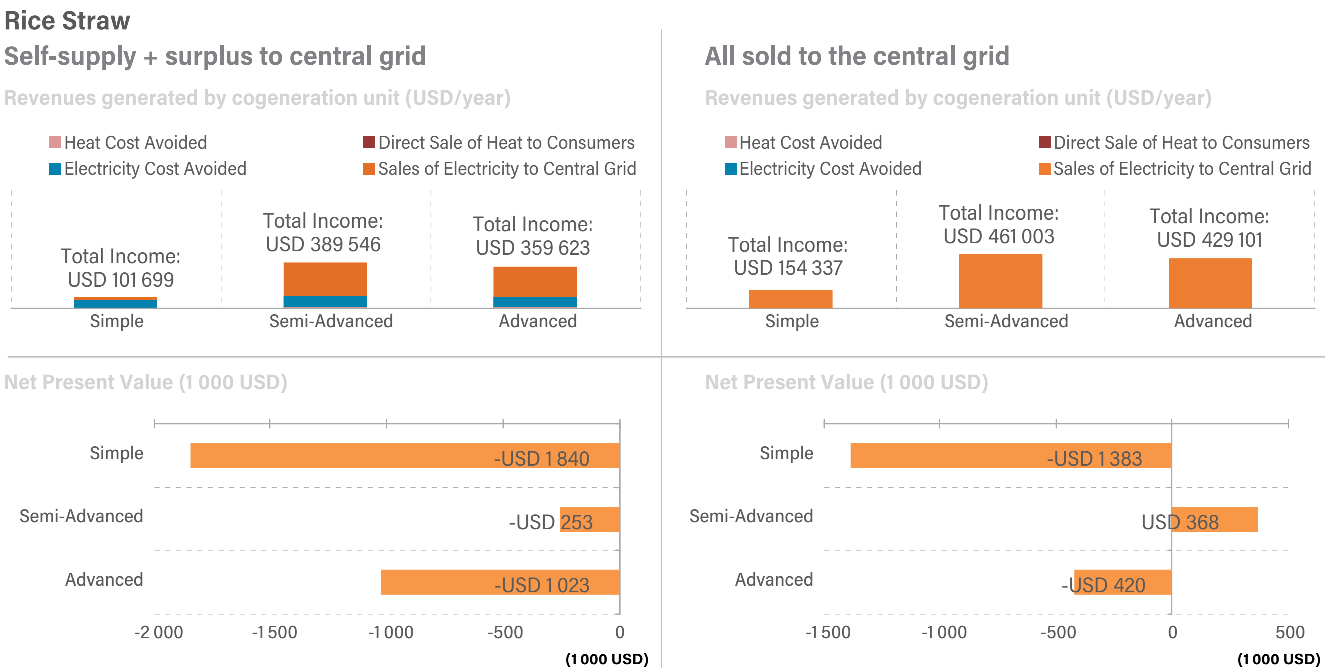


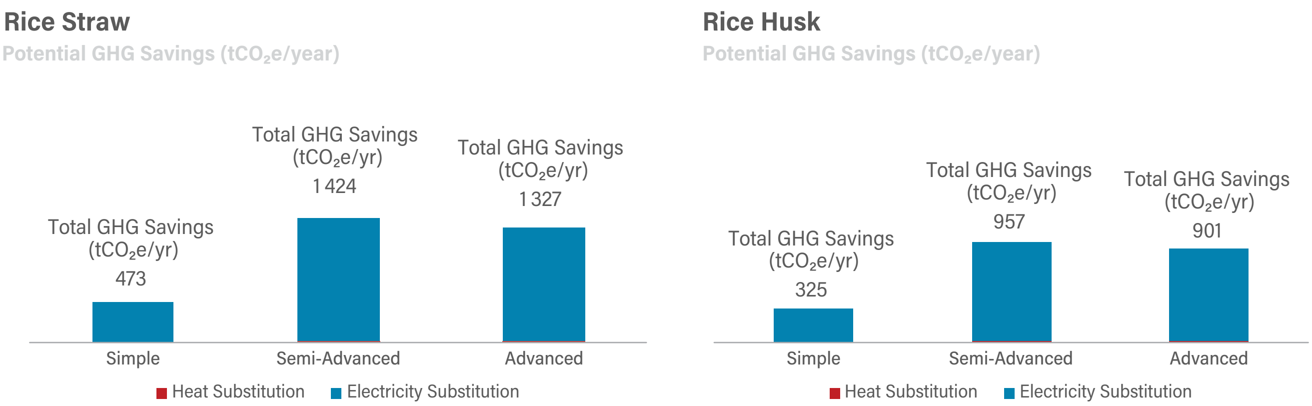
FIGURE 19. Comparison of revenues and profitability of electricity end use options – Rice Husk



Source: *Results from BEFS RA CHP tool*

Finally, the replacement of the coal used for heating and the central grid energy producing system, will bring environmental benefits in terms of GHG emission reductions. Emission reductions will be larger for CHP systems using rice straw given the large volume of this residue, compared to rice husk, see **Figure 20**. In terms of technology, the comparatively higher electricity generation capacity of the semi-advanced technology results in higher emission savings. Overall, rice straw in a semi-advanced technology set up allows the highest emissions reduction.

FIGURE 20. Comparison of GHG emission savings under electricity tracking mode



Source: *Results from BEFS RA CHP tool*

The above results show the potential to produce energy from rice straw and husk as well as the potential contribution to GHG mitigation. The results show that if all the accessible rice straw (22 383 tonnes/year) and rice husk (15 544 tonnes/year) is used for energy generation using a semi-advanced technology, it would be possible to produce at province level, a total of 5.5 MW and 8.0 MW from rice husk and rice straw respectively. This is equivalent to 13.3 MW of electricity, see **Figure 21**, which is 1.3 percent of the 1 000 MW national renewable target for biomass-fired electricity. Although 1.3 percent may seem small, it is the amount from just one mid-level mill in one province. This is an indicator of the high potential for biomass-based energy generation in Turkey. Moreover, the GHG savings achieved by replacing fossil fuels could reach a combined value of 39 105 tCO_2eq/year.

FIGURE 21. Generation capacity obtained from using all rice straw and husk available and accessible in Samsun

Source: *Own calculations based on the results from BEFS RA CHP tool*

Conclusions

This case study assesses the potential to generate energy from rice residues through a combined heat and power systems. The CHP analysis is site specific and was carried out for a rice mill in the province of Samsun, one of the top rice producing provinces of Turkey. The overall conclusion is that rice residues could represent an option to replace some of the fossil fuel consumption with bioenergy sourced from these residues. This should be done under a specific set of conditions and mostly by capturing the profit differences inherent in the discrepancies between the current price of electricity and the feed-in tariff.

In terms of feedstock availability, the analysis showed that as much as 111 917 tonnes of rice straw and 15 544 tonnes of rice husk could be available in the Samsun province. Nonetheless, this would need to be verified at the local level given accessibility constraints, especially in the case of rice straw. In fact, there is a crucial difference between the two residue types, as rice husk is the result of rice processing and is found in the mill with a zero-collection cost, while rice straw is spread over in the field (over the entire province of Samsun in this case) and would therefore have a collection cost attached to it. Therefore, the fact that the rice straw volume is spread across the province means that the costs of mobilization of this residue could represent a significant hurdle to the viability of using this residue type.

In addition, with respect to the CHP system set up, the analysis shows that an electricity tracking mode is preferred, allowing the mill heat demand to be covered and excess electricity to be sold to the grid. Of the technical set ups considered, the semi-advanced technology option is the only set up that would be marginally profitable at this stage. If, on the other hand, all electricity produced is sold to the grid, thus reaping the profit from the differences in electricity purchasing and selling prices resulting from the feed-in tariff, the CHP semi-advanced option would become profitable.

In terms of overall potential at province level, a total of 5.5 MW and 8.0 MW could be generated from rice husk and rice straw respectively with a reduction in emissions due to fossil fuel replacement.

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