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BEFS ASSESSMENT FOR EGYPT

Sustainable bioenergy options from crop and livestock residues

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ENVIRONMENT AND NATURAL RESOURCES MANAGEMENT WORKING PAPER

ENVIRONMENT CLIMATE CHANGE [ENERGY] MONITORING AND ASSESSMENT

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66

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Sustainable bioenergy options from crop and livestock residues

Food and Agriculture Organization of the United Nations
Rome, 2017

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CONTENTS

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ASSESSMENT SUMMARY

Context of the report and stakeholders

This report was developed under the collaborative agreement between the European Bank for Reconstruction and Development (EBRD) and the Food and Agriculture Organization of the United Nations (FAO), as part of the EBRD's Sustainable Resource Initiative, and building on FAO's Bioenergy and Food Security (BEFS) Approach. The Sustainable Resource Initiative falls under EBRD's new Green Economy Transition strategy. The BEFS Approach is part of FAO's Sustainable Bioenergy Support Package.

The Sustainable Resource Initiative supports policy dialogue by working with governments to strengthen institutional and regulatory frameworks that promote sustainable energy investment and explore options for transition economies to increase their use of renewable energy. Among the renewable energy options considered in this assessment are agricultural residues. The Shareholder Special Fund (SSF) is gratefully acknowledged for its support to the work and overall assessment carried out within this report.

The BEFS Approach and, within it, the BEFS Sustainable Biomass Assessment, are core elements of FAO's decision support package on sustainable bioenergy. The assessment will form the basis for the bioenergy policy process, by identifying which bioenergy options may be feasible within a given country, based on the country context, as well as on its conditions and energy and agricultural requirements.

The work was implemented in close collaboration with the Agriculture Research Centre (ARC), the New and Renewable Energy Authority (NREA), the Egyptian Environment Affairs Agency (EEAA) and the Ministry of Industry, with inputs from other national stakeholder and experts in the field of bioenergy, as listed in the acknowledgements section.

Scope and Structure

Egypt has a large agriculture sector and aims for renewable energy to account for 20 percent of its electricity generation by 2020. Moreover, there is a growing interest in reducing fossil fuel dependence and in finding substitutes for cooking fuels, such as Liquefied Petroleum Gas (LPG). The scope of this report is to provide an initial assessment of the viability of using available agricultural residues to produce energy in Egypt. The specific materials covered are crop and livestock residues. Given the interest in finding alternatives to support the renewable electricity generation targets and replace LPG, the energy end use options considered are briquettes, pellets, and combined heat and power (CHP) from direct combustion or from biogas.

The assessment adopted the tools and methodology of the BEFS Approach. The analysis is based on country specific data and conditions, and was carried out at governorate level.

Insofar as possible, the assessment built on previous analyses carried out in Egypt, together with ongoing efforts related to bioenergy potential assessment from agricultural residues.

The report is structured in four parts, including 1) a country overview focusing on the agriculture and energy sectors; 2) an assessment of the biomass potential; 3) an assessment of the energy end use options; and 4) a set of conclusions and recommendations for next steps based on the outcome of the analysis.

Country Context

The agriculture sector in Egypt still plays an important role in the national economy, contributing 14.5 percent to Gross Domestic Product (GDP) in 2014 and employing more than one–quarter of the labour force in 2013 (World Development Indicators, 2016; El–Nahrawy, 2011). Due to the size of agricultural production, a large volume of residues is generated from this sector each year. Open burning is the technique that is most commonly used to dispose of residues. It is estimated that approximately 52 percent of agricultural residues are burnt directly in fields or in inefficient burners (Nakhla, Hassan and El Haggar, 2013). Egypt is among the 11 fastest growing greenhouse gas (GHG) emitting countries in the world and the energy, industry, agriculture and waste sectors are the main contributors to these emissions (Climate Investment Funds, 2016; Nakhla *et al.*, 2013). As a result, there may be a case for using residues from the agriculture sector as feedstock for energy generation, and this forms part of the scope of the current report.

Egypt is a large producer of oil and dry natural gas in Africa, but it is also the region's leading oil and natural gas consumer (EIA, 2015). Oil products, natural gas, and electricity account for more than 95 percent of domestic energy consumption (IEA, 2016). Oil consumption currently surpasses oil production and demand continues to rise, along with demand for natural gas. In both cases, increases in consumption have been attributed to economic and industrial growth, energy intensive projects in natural gas and oil extraction, population growth, rise in sales of private and commercial vehicles and energy subsidies. As a result of this trend – and coupled with shortages in natural gas supply, crumbling infrastructure and inadequate generation and transmission capacity – Egypt experiences frequent electricity blackouts (EIA, 2015).

Energy subsidies have been partly responsible for the country's high budget deficit, and, in the fiscal year 2013–2014, they accounted for 22 percent of total government expenditures (EIA, 2015; IMF, 2014). In response, the Egyptian government introduced an energy subsidy reform that would reduce the subsidy to just 0.5 percent of GDP by 2019 (Ministry of Finance, 2015; James, 2015).

In addition, the Egyptian Ministry of Planning intends to maximize use of domestic traditional and renewable energy sources and for the country to become a pioneer in renewable energy (Ministry of Planning, 2016). Egypt aims to increase the installed capacity of renewable energy from 3 385 MW in 2012 to 11 320 MW for 2020, corresponding to 20 percent of its power generation (RCREEE, 2013b). The planned renewable energy mix will come from wind (12 percent), hydro (6 percent) and solar (2 percent) (Ministry of Electricity and Renewable Energy, 2012; EIA, 2015). The largest share will be contributed by wind power, since solar energy is estimated to be more expensive and the potential for hydropower has already been largely harnessed (African Development Bank, 2012). No specific plan or target is set for bioenergy.

More than 75 percent of Egyptian households rely on cylinders filled with LPG for cooking. The LPG price has a subsidy of 95 percent, but this is still a costly basic household item. Given the situation, the option of briquettes and pellets produced from crop residues was analysed in this assessment, together with their potential for meeting demand for cooking energy in Egypt.

Natural resource assessment

The main objective of the biomass assessment was to estimate the potential of agricultural residues for energy production, as well as their geographical distribution within Egypt. Two main agricultural residue types were considered: crop residues – which include prunings – and livestock residues. The table below lists all residue types.

RESIDUE TYPE	CROP OR LIVESTOCK FROM WHICH THE RESIDUE IS GENERATED
Straw	Wheat, rice, broad bean, barley, flax, lentil
Stalks	Maize, cotton, sorghum, sesame, sunflower
Prunings	Citrus/orange, palm dates, grapes, olives
Haulms	Sugar beet, peanuts, soybeans
Bagasse	Sugar cane
Manure	Chicken and cattle

The estimate of residue availability was based on data obtained through technical consultations with national experts. In this study, the focus was on estimating the production and availability of agricultural residues at governorate level.

The main methodological approach included three basic steps:

1. Assessment of production of residues: estimate of the total amount of residues generated as a result of agricultural production at country and governorate level.
2. Assessment of the availability of residues: estimate of the proportion of residues available for other uses, such as energy, once all current uses are accounted for, e.g. soil condition, etc.
3. Assessment of accessibility of residues: estimate of the amount of residues that could actually be accessed and used for the production of bioenergy, considering aspects such as collectability and mobilization of the biomass.

The assessment covered steps 1 and 2. Step 3 was discussed in general terms.

Crop residues

The selection of crop residues was based on the scale of production of the specific crop, as well as on suitability of the residue for the selected bioenergy technology (briquettes, pellets and CHP from direct combustion or from biogas).

At national level, the total residue produced for all the selected residue types was estimated to be around **30 Mtonnes/year**. A large portion of these residues consists of those from cereals (67.6 percent), with wheat straw making up the largest share (37.7 percent), followed by maize stalk (16.6 percent) and rice straw (10.7 percent). Other notable crop residues come from sugar crops, with sugar cane bagasse contributing to around 11 percent of total national crop residue production, followed by sugar beet haulm with 4.2 percent of total residues. Fruit tree prunings contribute 12.3 percent to national residue production.

The actual amount of residues available for bioenergy production depends on current uses of these residues in Egypt. In order to estimate the availability of crop residues for bioenergy production, current use practices for each residue were discussed and agreed upon with the Egyptian Agriculture Research Centre (ARC). Following this stage, the total quantity of residues available for bioenergy production was estimated to be around **5 Mtonnes/year. Maize stalks, rice straw, sugar cane bagasse** and **cotton** stalk were the country's top four residue types, each with availability of more than 500 000 tonnes/year. These four types account for around 80 percent of total availability potential in the country. At regional level, the highest availability of residues is found in the Middle Delta region, followed by the Upper and Middle Egypt regions, each having more than 0.8 Mtonnes of residues per year available for bioenergy. The governorates of **Behera, Sharkia, Dakahlia** and **Kafr–El Sheikh,** all in the Middle Delta region, have the largest aggregated availability of residues in Egypt, each offering availability of between 0.59 and 0.87 Mtonnes of residues per year.

Among the four most commonly found residues in Egypt, maize stalk, rice straw and cotton stalk are most available in the Middle Delta region, while sugar cane bagasse is most available in the Upper Egypt region.

In addition to these residues, prunings from the various types of fruit production are promising feedstocks for bioenergy production, given their physical characteristics and high calorific values. The total availability of prunings from citrus fruit, olive, grape and palm date production was estimated to be around 777 000 tonnes. The Middle Delta region has the highest share of prunings, with 58 percent of total availability concentrated in the region. This region also has the highest availability of each pruning type, with the exception of those from olives. Olive prunings are mostly concentrated in the coastal region, accounting for 55 percent of availability.

Livestock residues

Livestock residues consist of manure from cattle (cow and buffalo) and chicken (layers and broilers).[1] In terms of production, the analyses estimated that, at national level,

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[1] Sheep and goat manure is not suitable, since it cannot be collected, although it may be feasible at very small scale, which is beyond the scope of this assessment.

approximately 57 Mtonnes of cattle manure and around 6 Mtonnes of chicken manure are produced each year.

At regional level, the Middle Delta region has the highest cattle manure production of all regions, with total production of 31 Mtonnes/year, making a 55 percent contribution to total manure production in Egypt. This region is followed by the Upper Egypt region, with production of 13 Mtonnes (23 percent), and the Middle Egypt region, with production of 10 Mtonnes (19 percent) of cattle manure per year.

Cattle manure is often used as soil amendment and may have other uses depending on local practices. Based on discussions with national experts, the total amount of manure available for bioenergy use was estimated to be around **14 Mtonnes/year**. The availability of cattle manure is highest in the Middle Delta region, at 7.8 Mtonnes/year, accounting for approximately half of overall availability.

At governorate level, **Behra** and **Sharkia** have the largest availability of cattle manure, with 2.1 Mtonnes and 1.4 Mtonnes of manure available annually. Together these two governorates constitute 25 percent of total cattle manure availability in Egypt. In addition, out of 27 governorates, 12 show availability of between 0.5 and 1 Mtonnes of manure, while 12 others have less than 500 000 tonnes of manure available per year.

Accessibility of livestock residue depends largely on rearing practices, farm size, infrastructure (manure management systems), etc. In general, larger farms can provide larger amounts of manure, so in some cases, even one feedstock supplier could be enough to run a biogas plant, which generally simplifies the implementation of such a bioenergy project. In the light of this, data on cattle farm sizes per governorate were collected. The analysis shows that cattle farms with the highest shares of larger farms (50 heads and over) are found in Behera, Sharkia, Fayoum, Qalyoubia and Suhag. The final availability estimate was 6 Mtonnes/year, when considering larger–sized farms.

For chicken manure, the analysis was divided into broilers and layers, due to differences in the physical and chemical properties of their manure. The vast majority of broiler farms are located in the Behera governorate (57 percent of total broiler farms), while layer farms are mostly found in Sharkia, Qalyoubia and Gharbia (70 percent of total layer farms).

It was estimated that around **6.3 Mtonnes** of chicken manure is produced each year, of which broiler manure accounts for some 96 percent. The top two governorates with the highest production of broiler manure are Sharkia and Minya, together contributing 35 percent to total broiler manure production. The governorate of Sharkia also has the largest share of production of layer manure, accounting for 24 percent of total output.

As in the case of cattle manure, technical consultations were conducted with national experts to understand current management and use practices for chicken manure. These indicated that only 0 to 5 percent of chicken manure might be available for new bioenergy projects. Overall, this led to the conclusion that no chicken manure could realistically be considered to be available for bioenergy production at this level of analysis. It might be possible to find pockets of availability of chicken manure, but estimates were not possible at this stage.

In conclusion, as a result of the crop residue assessment, maize stalks, rice straw, sugar cane bagasse and cotton stalk, prunings from certain fruit trees and cattle manure have been identified as biomass sources that could potentially be used to produce bioenergy in Egypt. The Middle Delta region appears to be the most promising area, as far as total availability of residues is concerned. At governorate level, **Behra, Sharkiya, Dakahlia** and **Kafr–El Sheikh** appear to be the most suitable locations to pilot a bioenergy project, given the greater availability of both crop and livestock residues there.

ENERGY END USE OPTIONS ASSESSMENT

An assessment was carried out of the viability of selected bioenergy technologies – namely direct combustion and biogas–based CHP, as well as briquettes and pellets – based on the biomass assessment. The aim of this part of the assessment was to identify potentially profitable and technically feasible combinations of energy production based on the biomass amounts available. In addition, the assessment quantified the extent to which these options could help to meet the renewable electricity targets set by Egypt, or be used to supply biomass as an alternative to LPG. In order to have a general sense of the potential of using biomass for electricity generation or for cooking, the total biomass calculated to be available was first used to estimate the total maximum electricity potential, and then used to estimate the total maximum amount of LPG that could be substituted. The final results of the assessment show which option could be most profitable for which location.

Combined heat and power (from biogas or through direct combustion)

Biomass–based combined heat and power (CHP) production was assessed for the production of electricity and compared to the renewable electricity targets in Egypt. The economic viability and sustainability of a CHP plant depends on various factors, including levels of availability and access of residues, technology used and the scale of production. Although all these variables were considered in this analysis, the most critical factor affecting the viability of CHP plants is the selling price of electricity.

Three scenarios were considered in terms of the selling price of electricity. The first price (Scenario 1) is 0.05 US$/kWh, which represents the weighted average price of electricity for 2016–2017. The second price (Scenario 2) is 0.1 US$/kWh, which is the feed–in tariff price. The third comparison price (Scenario 3) is 0.15 US$/kWh, which considers an additional 50 percent premium[2], in addition to the current feed–in tariff price. The results of the assessment show that CHP schemes would start to be economically viable from a selling price of 0.10 US$/kWh.

In addition to the selling price, another element that allows improved economic viability of a bioenergy plant is minimizing the cost of the residue. The results indicate that under a direct combustion scheme, the maximum payable price ranges from

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[2] The average price of electricity was calculated for the period based on data from the Egyptian Electric Utility and Consumer Protection Regulatory Agency (EgyptERA, 2016). The feed in tariff was considered to be 0.10 US$/kwh based on the information available at the time of the analysis. This is in line with the feed in tariff proposed by the Council of Ministers for Egypt in decision number 5/10/15/4 dated 28/10/2015, where it is stated that the feed in tariff will be 0.92 EGP/kWh (Council of Ministers for Egypt, 2015), as reported by NREA.

41 to 61 US$/tonne under Scenario 2. Consequently, CHP plants should be developed close to or attached to agroprocessing facilities. This would allow the use of freely available feedstock and/or minimize collection and transport costs. Such a scheme would enable the CHP plants to supply heat and electricity to the agroprocessing plant. Any surplus electricity could then be sold to the central grid.

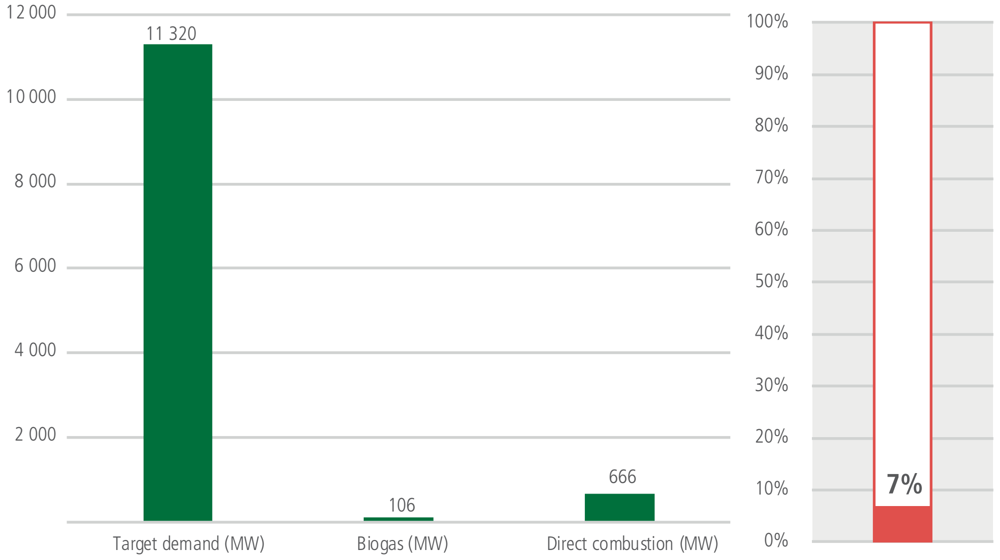
Under this set of profitable production conditions, the feedstock that met the technical requirements for direct combustion in CHP plants included maize stalk, rice straw, citrus prunings, olive prunings, palm date prunings, cotton stalk, grape prunings and sugar cane bagasse.

For biogas–based CHP plants, the limited availability of manure identified in the biomass assessment component means that biogas–based CHP plants based on manure only are not feasible at industrial level. However, biogas–based CHP plants that use a combination of manure and crop residues could be profitable, depending on the type of feedstock combination used and their collection source. Thus, among the available feedstock options, the most suitable combination would be a mix of cattle manure, sunflower stalk and sugar beet haulm. This type of biogas–based CHP plants would need to aim for stand–alone operation, given that these plants will require multiple biomass suppliers. In this case, the maximum payable feedstock price that these plants might accept ranges from 1.8 to 32.3 US$/tonne for production scales varying from 250 to 50 000 kWe. Therefore, locally designed supply chain models might be required to define the optimal locations of biogas to CHP plants and feedstock collection points. Additional analysis would be required to identify potential consumers for the heat produced by these plants and to examine the alternatives of converting heat into additional electricity or cooling.

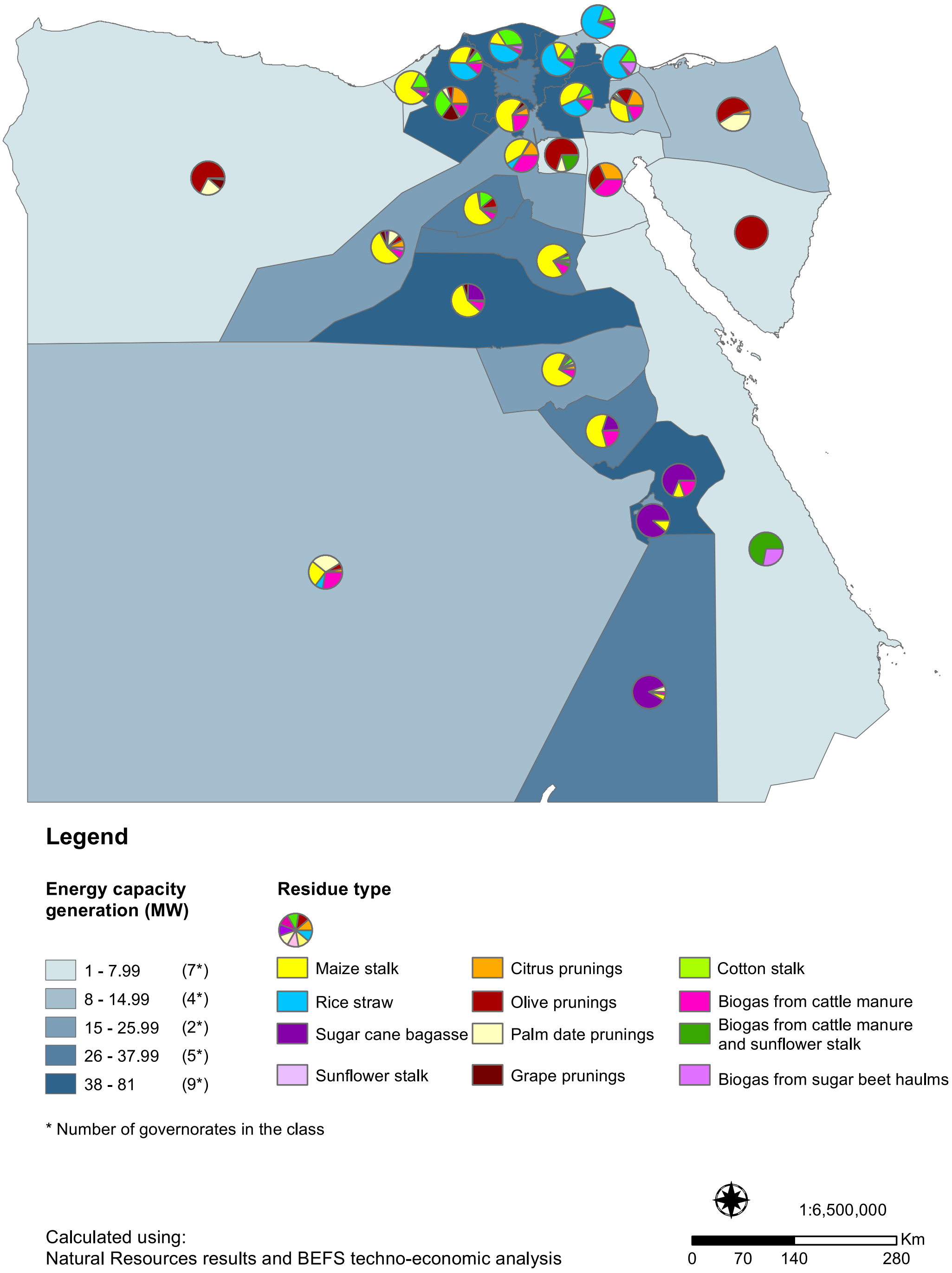
Assuming that all the available biomass were accessible, and that logistics were in place, if all the biomass available were dedicated to electricity generation with CHP technologies, it would be possible to reach a maximum potential of **772 MW** as the **combined generation capacity of all the governorates**. This potential could cover **7 percent of the 11 320 MW renewable energy target**, supply more than 2.2 million households and avoid **2.9 million tonnes CO_2eq/year.**

The figure below summarizes the potential electricity generation capacity of CHP plants based on biogas and direct combustion. The governorates of **Sharkia, Dakahlia, Behera, Kafr El Sheikh, Menia** and **Qena** are the most promising areas, where it may be possible to establish the largest profitable plants. Overall, higher generation capacities are generally found around the Nile River areas, where the country is more industrialized. The feedstocks with the highest potential for energy generation in Egypt are rice straw in the north, maize stalk in the middle and sugar cane bagasse in the south, all through direct combustion.

Contribution to Egyptian 2020 renewable energy targets



Total potential electricity generation using CHP technologies



Calculated using:
Natural Resources results and BEFS techno-economic analysis

Briquettes and pellets

The second energy end use alternative considered in this study is to use the available agricultural residues as an option to supplement some of the cooking energy demand in Egypt by replacing LPG. In terms of briquettes and pellets, the economic profitability will depend on the market price that these producers will receive. In this sense, there would be two possible comparison prices. The first is the current market price, which is 8.4 US$/GJ for briquettes and 7.6 US$/GJ for pellets. Briquettes and pellets are currently mostly used by high–income households on barbeque fires, or sold to the export market. The second comparison price is the equivalent price of LPG (the subsidized LPG price), which is LPG 4.3 US$/GJ.[3]

Results of the profitability assessment illustrate which briquette and pellet options may be feasible under current market conditions.

In the case of briquettes, the analysis shows that the maximum selling price can range from 18 to 62 US$/tonne. The variability in the selling price is a result of the spectrum of feedstock energy potential and the plant size. Conversely, pellets would reach maximum payable prices ranging from 27 to 93 US$/tonne. However, due to the need for a higher initial investment than for briquettes, only large–scale operations would be profitable. Overall, briquettes require a lower capital investment, but are slightly less efficient than pellet technologies. These in turn require a higher initial investment, but due to their greater efficiency are able to reduce operation costs and be more cost effective at levels of large–scale production.

The feedstock found to be most promising for briquette and pellet production were prunings from citrus fruits including oranges, olives, palm dates and grapes, as well as cotton stalk, sugar cane bagasse, sunflower stalk, maize stalk and rice straw.

Based on these results, an effective approach to using agricultural residues for briquette and pellet production would involve prioritizing briquette technologies at small–scale operation, and those of pellets at large–scale operation.

Again, assuming that all the available biomass were accessible and that logistics were in place, if all these crop residues were converted to briquettes/pellets, it would be possible to achieve a combined potential energy output of 1 878 ktoe/year. When comparing this potential to the LPG consumption figures reported by Energy Information Administration (EIA) (2010–2012) of 6 115 ktoe/year (EIA, 2016), it may be possible to replace 31 percent of LPG consumption by briquettes and pellets, supplying more than 1.6 million households and avoiding 3.6 million tonnes CO_2eq/year.

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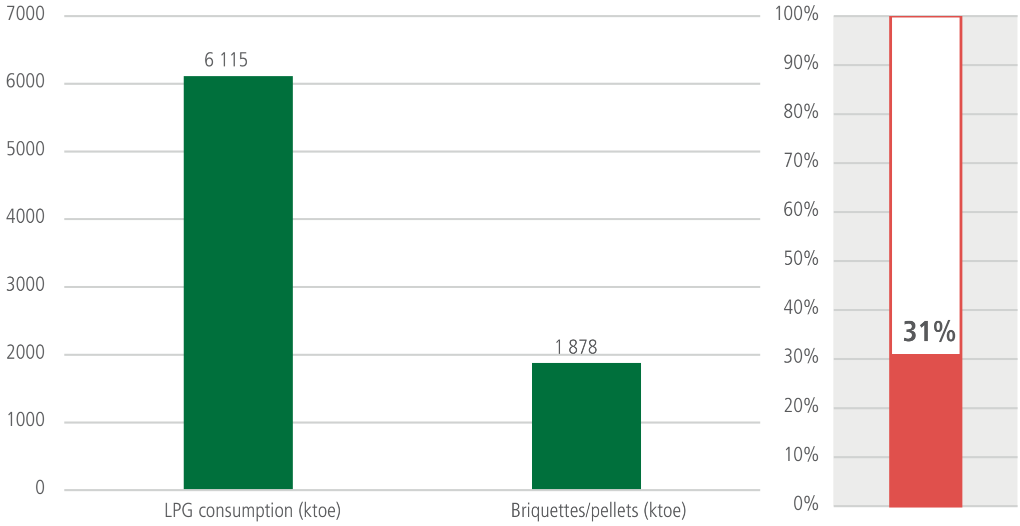
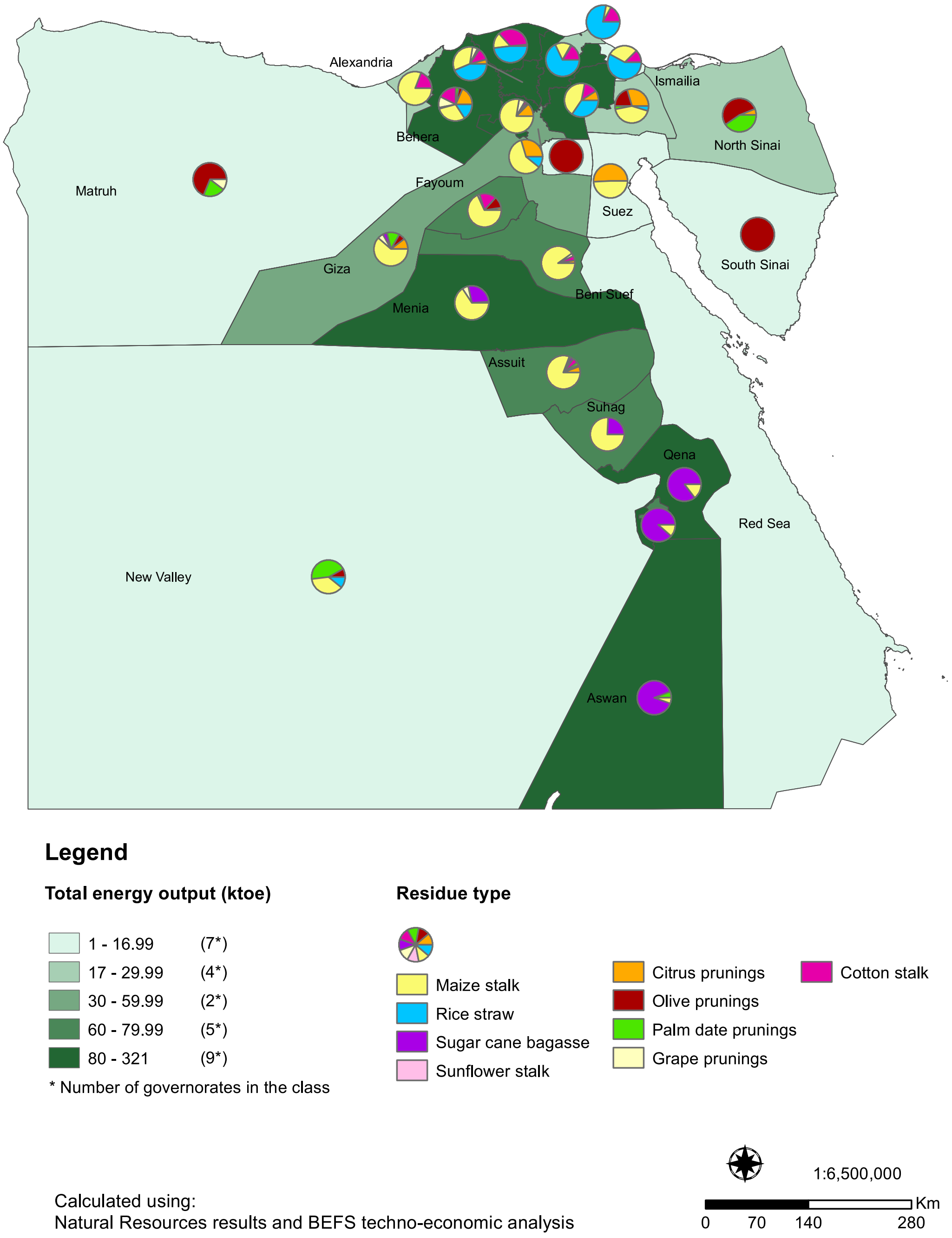
[3] Please note that all prices were converted to energy equivalent units (GJ) to simplify their comparison. Current prices in their original units are: briquettes (175 US$/tonne), pellets (119 US$/tonne) and LPG (0.997 US$/cylinder).

Potential contribution of briquettes and pellets to replacing LPG consumption



Total energy output using briquette/pellet technologies



Calculated using:
Natural Resources results and BEFS techno-economic analysis

In general terms, results of this assessment show that using agricultural residues for energy production as electricity (CHP technologies), or as cooking fuel replacement (briquettes/pellets), can result in promising cost–effective options to increase energy access, reduce fossil fuel dependence and GHG emissions and contribute to renewable energy targets. To date, the feedstock options considered have been the same for both CHP and briquettes and pellets. Therefore, the final decision on which combination to use at governorate level will depend on local availability and accessibility of residues, and specific energy demand in each governorate.

Conclusions and Recommendations

Overall, the analyses indicate that Egypt has the potential to produce sustainable bioenergy, especially from crop residues, which can help the country to meet its energy demand while contributing to achieving its renewable energy and GHG emission reduction targets. Maize stalks, rice straw, sugar cane bagasse, cotton stalk, prunings and cattle manure can be used to produce sustainable bioenergy in Egypt. The Middle Delta region appears to be most promising as far total availability of residues is concerned. At governorate level, **Behra, Sharkiya, Dakahlia** and **Kafr–El Sheikh** are the most suitable locations to pilot a bioenergy project, due to substantial availability of both crop and livestock residues.

However, it is important to reiterate that the potential to produce bioenergy depends largely on the actual availability and accessibility of residues, as well as on their geographical distribution. Therefore, a next step would be to validate the biomass availability and accessibility of the residues in the most promising governorates identified in this assessment.

After that, the following recommended stage would be to carry out a few selected pilot projects in the governorates where the highest potential has been identified. Five proposed options are listed below:

CHP using rice straw:

Rice straw in CHP plant attached to rice mills. In this way, the CHP plant would benefit from a continuous supply of rice straw and the rice mills could become a potential buyer for the heat and electricity produced. From a biomass point of view, the optimal location for this first trial could be in **Dakahlia** or **Kafr–El Sheikh** governorates. A more detailed verification of rice straw availability should be performed, considering other potential uses, such as animal feed.

CHP using maize stalk:

In the central part of the country, there is good availability of maize stalk residues, particularly in the **Menia** and **Sharkia** governorates. However, the high collection costs of this feedstock have a negative impact on profitability of CHP plants. It would therefore be necessary to conduct a field analysis in the specific governorates to help estimate the detailed collection costs and gain an understanding of the possibility of using this residue in CHP plants attached to maize mill industries.

CHP from sugar cane bagasse:

Energy production using sugar cane bagasse is a well–known technology applied in sugar mills. This feedstock is a very promising option, given its good availability and the absence of collection costs. A field analysis in the Upper Egypt region is needed to understand why sugar mill industries are not currently using this residue. Results of the assessment would provide a first indication that this option would be beneficial for sugar mills, allowing them to benefit from the energy potential of this residue type. The two potential governorates would be **Qena** and **Aswan**.

Biogas from cattle manure:

Cattle manure is still an attractive option for biogas–based CHP. Additionally, under codigestion, this residue can be used for biogas production together with crop residues that are available, but in smaller amounts. Using cattle manure would increase biogas generation capacities in the country. Locating CHP plants attached to food processing industries may not be the most cost–effective option, since residue collection may need to be conducted from multiple sources. As a result, the location of these plants would depend mostly on the biomass supply. Consequently, biogas to CHP producers would not necessarily have an industry outlet to which they could sell the heat produced. Alternatives for using the surplus heat produced would therefore need to be found in order to ensure economic viability. A field level analysis would be required to define the most cost–effective option to use this heat, either as cooling or for the generation of additional electricity, depending on specific local energy needs. Potential governorates would be **Behera, Menoufia** and **Beni Suef**.

Briquettes and pellets for cooking (to substitute LPG) from prunings:

Briquettes and pellets are the most flexible option, in that they can use different feedstock types and operate at various plant size levels. Given the size restrictions highlighted in the report, briquette and pellet production may represent an attractive option to promote cost–effective LPG replacement and create self–supply energy solutions. The most favourable governorate for an in–field small–scale briquette project could be **Behera, Ismailia** or **North Sinai**, using olive, citrus and palm date prunings.

Finally, consultations held in the country reveal that the biggest bottleneck is the timely mobilization of biomass. Therefore, efforts should focus on mobilizing identified biomass resources, starting with the above list as the initial locations.

Based on all the above, recommendations for the next immediate steps are the following:

- Using the list above, identify a set of pilot phase projects to test the feasibility at field level of bioenergy supply chains targeted.
- Move to field level and verify the availability and accessibility of identified residues at local level, together with related constraints.
- Meet local stakeholders to discuss viability of the identified supply chains and bottlenecks that obstruct implementation.

The overall aim is to develop a well–functioning biomass value chain – covering collection, storage and transportation, pre–treatment and energy processing – that can enable a steady, long–term and reliable supply of biomass for bioenergy production.

CHAPTER 1

NATURAL RESOURCE ASSESSMENT

The main objective of the natural resources assessment within this study is to estimate the biomass potential for energy production at governorate level in Egypt. The biomass potential here refers to agricultural residues, i.e. crop and livestock residues.

The assessment starts by defining two main criteria:

- Geographical scale
- Crop residue types and animal categories

METHODOLOGY FOR THE ASSESSMENT

Biomass is highly diverse and one of the most complex renewable energy sources, with a strong relation to the spatial aspect. This is reflected in the geographical representation/ distribution of the estimated potential, which can be developed at national level and at all scales of subnational level, depending primarily on the purpose of the assessment. Bioenergy potential estimated at national level can provide an indication of business opportunities. However, a detailed subnational level assessment represents a stronger indication for more practical implementation of the estimated potential. There are examples where a significant biomass potential has been estimated on a national level, but when analysed at a higher spatial resolution, the potential is actually scattered and fragmented to such an extent that in practical terms, harnessing this potential for energy production would be very difficult and unlikely. In this study, the focus on the biomass potential estimate was directed at governorate level. Later on, using a bottom–up approach, regional and national level estimates were provided. It is important to note that official Egyptian agriculture statistics present data for 28 governorates, one being Noubaria. After technical consultations with the national stakeholders, it was concluded that Noubaria is actually not a formal governorate, but rather a very specific zone within the Behera governorate. Noubaria's special status is due to its very specific soil type and climate characteristics, which make it highly productive from an agricultural point of view. Therefore, the spatial representation of the biomass potential in this study follows with a list of the 27 formal governorates in Egypt. In terms of regions, considering the nature of the assessment and the fact that biomass distribution is not linked to administrative borders, regions were formed based on agro–ecological zones in Egypt. Again, Noubaria, although geographically belonging to Behera governorate, is part of the Newly Reclaimed Lands in terms of regions. This needs to be taken into account when analysing data and figures within the chapter on natural resource assessment. Figure 1 shows a map of Egypt with the respective regions and governorates, while Table 1 lists these.

FIGURE 1.

Map of Egypt: Governorates and regions

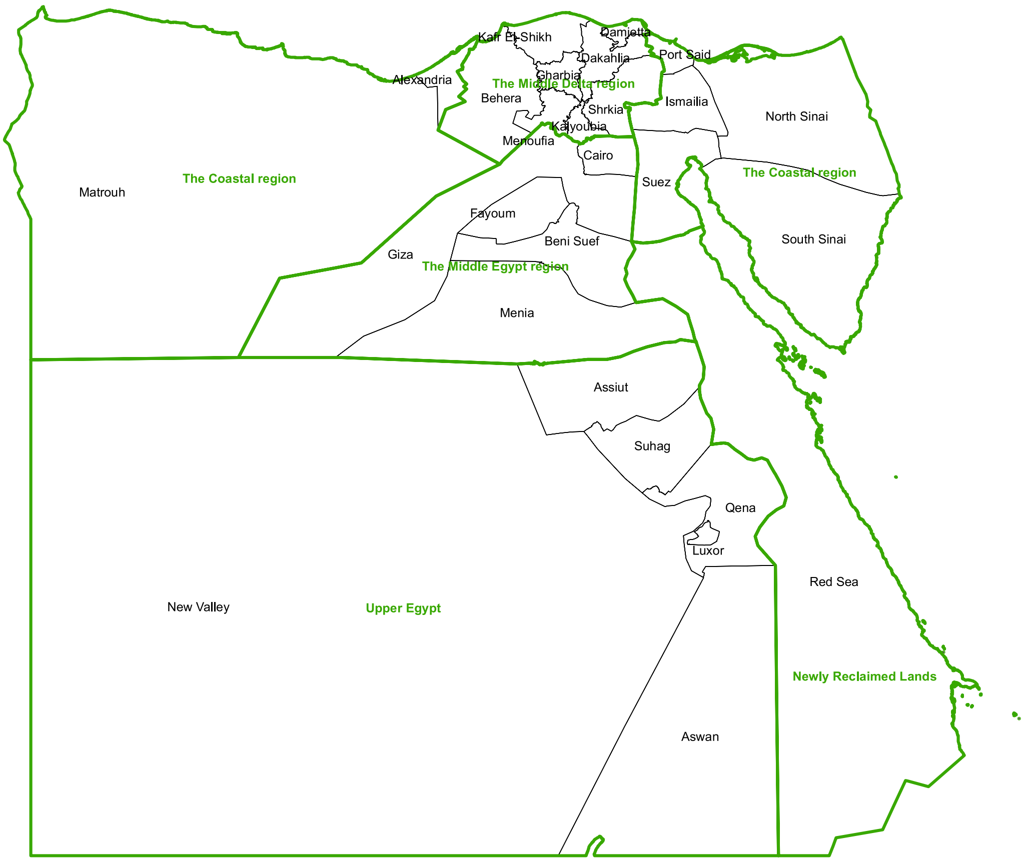


TABLE 1.

Regions and governorates in Egypt

REGION	GOVERNORATE
Middle Delta	Qalyoubia
	Menoufia
	Gharbia
	Dakahlia
	Kafr–El Sheikh
	Behera
	Sharkia
	Damietta

REGION	GOVERNORATE
Middle Egypt	Cairo
	Giza
	BeniSuef
	Fayoum
	Menia
Upper Egy	Assuit
	Suhag
	Qena
	Luxor
	Aswan
	New Valley
Coastal Region	Port Said
	Ismailia
	Suez
	North Sinai
	South Sinai
	Alexandria
	Matruh
Newly Reclaimed Lands	Red Sea
	Noubaria

A number of the crops grown in the country are potentially suitable for providing residues for energy production. Nonetheless, the final selection of such crops, whose residues were analysed in the study, was carried out based on two criteria:

- the scale of production of the specific crop in Egypt;
- the suitability of their residues for the production of briquettes and pellets, as well as for their use as feedstock for combustion, CHP and/or biogas technologies.

Both criteria are equally important, since residues that are produced on a large scale, but are not suitable feedstock – and vice versa – will not make a substantial contribution to bioenergy production.

In the context of assessing the potential of livestock residues (i.e. manure excreted by animals) for energy production, it is important to define which animal categories were the focus of the analysis. There were two primary criteria in the assessment:

- the share of each animal category within the whole national livestock fund;
- the assumption of potential manure collectability (stable reared animals).

In general, the greater the share of certain animal categories (e.g. cattle) in the livestock fund, and the greater the assumed share of stable rearing practices, the more reason there is to include corresponding livestock residues in the biomass potential estimate. In the light of this, together with the particular circumstances of Egypt, the assessment of livestock residues' bioenergy potential refers to manure excreted by cattle and chicken.

After taking this into account, three basic steps were examined:

1. Assessment of residue production
2. Assessment of residue availability
3. Assessment of residue accessibility

In this study, the focus was on the production and availability of agricultural residues at governorate level. The latter can be referred to as the theoretical and technical biomass potential, respectively.[4] Accessibility is described and explained in a more qualitative manner, since this particular step requires highly detailed data on a high–resolution spatial scale.

Finally, it is important to emphasize that if necessary (i.e. technically required/ justifiable), the estimate of agricultural residues' potential adopts a conservative approach, with the main purpose of avoiding overestimates.

GENERAL OVERVIEW OF THE DATA COLLECTION PROCESS

Data for the estimation of bioenergy potential from agricultural residues were obtained from the Egyptian Agriculture Research Centre (ARC) and FAO Egypt. The data collection process also included direct consultation with ARC experts and technical consultations with ARC.

During the technical consultations, the following aspects and issues were discussed:

Crops	Crop statistics with support of the national bulletins (MOALR)
	The list of crop residue types
	Agricultural seasons
	Residue–to–crop ratio (RCR)
	Competing uses of selected residues (availability)
	Differences across the country
Livestock	Cattle number
	Cattle and chicken manure production per head
	Cattle and chicken number of farms
	Current uses of cattle and chicken manure (availability)
	Differences across the country

The consultations represented an essential part of the data collection process, enabling the results of the assessment to reflect Egyptian circumstances and characteristics.

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[4] There are several types of biomass potential, such as theoretical, technical, ecological, etc. The terminology depends on the methodology. Each type has its own range, scope and practicability indication level. Therefore, within every biomass potential assessment, it is very important to note which type of biomass potential the results presented correspond to.

CROP RESIDUES

Methodology

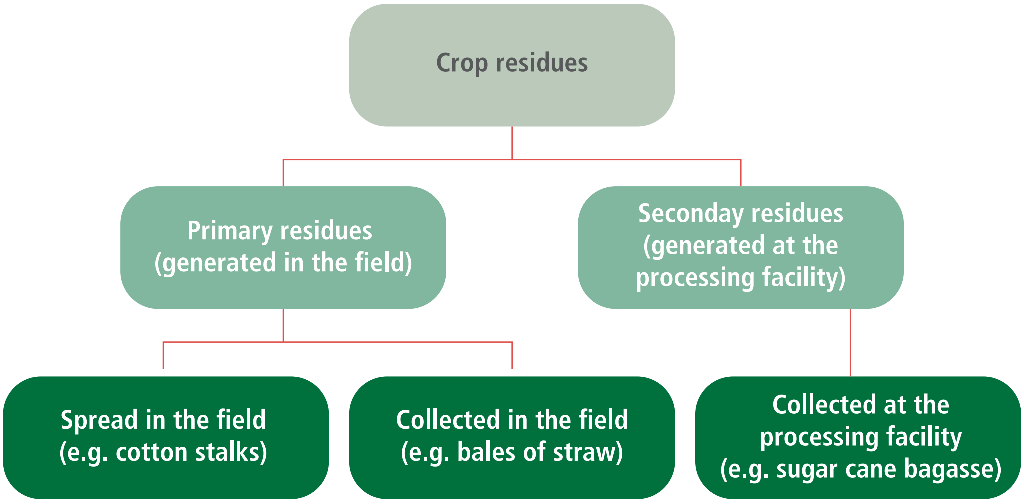
Production of crop residues

Crop residues are the organic material produced as by–products from harvesting and processing of agricultural crops. Residues are further categorized as primary and secondary (Figure 2).

- Primary residues are those generated in the field at the time of harvest. They can then be collected in the field, as in the case of cereal straw (when baled), or be spread in the field, as in the case of sugar cane tops, cotton and maize stalks.
- Secondary residues are those that are coproduced during processing. These include: paddy husk, sugar beet bagasse, maize cob, coconut shell, coconut husk, etc. Secondary residues are collected at the processing facility.

FIGURE 2.

Crop residue types and location



Most of the crop residues investigated in this study are primary residues generated in fields – straw and stalks that are spread or collected, including prunings from some fruit trees. The only exception is the dry pulpy residue left after the extraction of juice from sugar cane, known as bagasse, which is collected at the processing facility.

Among the many crops produced in the country, those selected were identified for their significant production of residue and their characteristics, taking into account their economic value.

The basic calculation for residue production followed this equation:

Equation 1

$$CR_{tot} = 0.42 \text{ x } CR_{rate} \text{ x } Area_{cult}$$

Where:

CR_{tot} *[tonnes/year]* = Total crop residue production per year

CR_{rate}*[tonnes/ha*year]* = Production rate of crop residue per unit of area per year (specific for each crop)

$Area_{cult}$*[feddan]* = Cultivated area

The production rate of crop residues was calculated, per unit of area (feddan) and season, as an average of different estimates resulting from practical measurements in the field, integrated with information collected from various publications. The production rate of each crop residue was also used to derive the Residue–to–Crop Ratio (RCR) for each crop.

Besides being classified by their geographical distribution (agricultural regions and governorates), crop residues were also classified according to their cultivation season. Three agricultural seasons can be identified for Egypt:

1. Summer season (April–October)
2. *Nili* Season (July–October)
3. Winter Season (November–April)

The summer season partially overlaps with *nili* (within the same year), whereas winter spans two consecutive calendar years. Sometimes, summer crops may also be collected during the nili season. Certain cereals, such as rice and maize, and some oilseeds, such as sunflower and soybean, are examples of such crops. The annual residue production in these cases is the sum of the seasonal values.

Availability of crop residues

Having estimated crop residue production, the next step is to quantify residue availability, which refers to the actual amount of residues potentially available for bioenergy production, net of all other competing uses, including surface cover for soil quality preservation.

The basic equation to calculate residue availability is the following:

Equation 2

$$CR_{bioen} = (CR_{tot} - CR_{soil} - CR_{used})$$

Where:

CR_{bioen}*[tonnes/year]* = Crop residues potentially available for bioenergy

CR_{tot}*[tonnes/year]* = Total production of crop residues

CR_{soil}*[tonnes/year]* = Amount of crop residues used for the soil

CR_{used}*[tonnes/year]* = Amount of crop residues already used for other purposes

A variable portion of crop residues is usually left in the field, mainly at harvest time, as one of the good practices of planned systems for soil conservation. The residue left on the surface adds organic matter to the soil as it decomposes, and shields soil particles from rain and wind, preventing soil erosion.

Besides soil protection, crop residues are also used in varying degrees for other purposes, particularly among rural communities. Straw, for example, is commonly used as animal fodder and bedding, sometimes mixed with animal dung to prepare compost, or blended with cement for brick–making. Similarly, stalks are largely used as animal fodder and in some rural communities, as a protection belt around vegetable fields, as material to protect houses, or as a source of energy for cooking. Fruit tree prunings are another common source of domestic energy, but they are also used in wood manufacture and rural constructions.

Finally, crop residues that are potentially available for bioenergy only represent the share of estimated total residue production that is not already allocated to other current uses.

Data collection

The scale of production, indicated by the amount (tonnes) of crop produced and the corresponding harvest area (hectares) per governorate, was obtained from the Bulletins of the Agricultural Statistics (MOALR).[5] Information on residue production was provided by the Egyptian Agriculture Research Centre (ARC), which applied the abovementioned equation based on the crop residue production rate. Table 2 presents the list of selected crops and corresponding residues by season, along with the production rate per unit of area, expressed as air dried material.

TABLE 2.

Production rate of crop residues per feddan as air dried material for crops selected

SEASON/ CROP	SUMMER			WINTER			NILI		
	Crop	**Residue**	**t/fed**	**Crop**	**Residue**	**t/fed**	**Crop**	**Residue**	**t/fed**
Cereals	Rice	straw	2.20	Barley	straw	1.90	Rice	straw	2.20
	Maize (white & yellow)	stalk	2.10	Wheat	straw	3.50	Maize (white & yellow)	stalk	2.10
	Sorghum	stalk	1.78				Sorghum	stalk	1.78
Oilseeds	Soybean	haulm	1.12						
	Peanut	stalk	1.02				Peanut	stalk	1.02
	Sesame	stalk	1.39				Sesame	stalk	1.39
	Sunflower	stalk	2.35				Sunflower	stalk	2.35
Pulses				Broad bean	straw	3.50			
				Lentil	straw	1.13			
Sugar crops	Sugar cane	bagasse	10.30						
	Sugar beet	haulm	3.00						

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[5] Ministry of Agriculture and Land Reclamation, Economic Affairs Sector, Bulletins of The Agricultural Statistics, 2014.

SEASON/ CROP	SUMMER			WINTER	NILI
Fruit	Citrus	pruning	3.90		
	Grapes	pruning	3.90		
	Olive	pruning	3.90		
	Palm dates	pruning	7.50		
Fibres	Cotton	stalk	1.70		
	Flax	straw	2.40		

The overall information received from the country was analysed and discussed with the ARC during the BEFS technical consultations and through direct communication. At the end of this process, the three–year period (2011–2013) was used as a basis for the analysis.

Production of crop residues

In line with the methodological approach, the estimate of crop residue production in the period 2011 to 2013 required use of the following datasets (in brackets, the respective sources):

- The scale of production of the specific crop, for each year in the period 2011 to 2013 (MOALR, 2012–2014 – Bulletins of the Agricultural Statistic);
- Cultivated area of each crop selected per governorate, for each year in the period 2011 to 2013 (MOALR, 2012–2014 – Bulletins of the Agricultural Statistic);
- Production rate of residues per unit of area for each crop selected (ARC, 2015).

The scale of production is a valuable element for identifying the most interesting crops in terms of residue source. Figure 3 and Figure 4 below display the first eight of such crops with the highest production (>1 Mtonnes/year) and those with a production average of between 100 000 and 1 Mtonnes/year, both at national level.

FIGURE 3.

Crops with average production higher than 1 Mtonnes/year

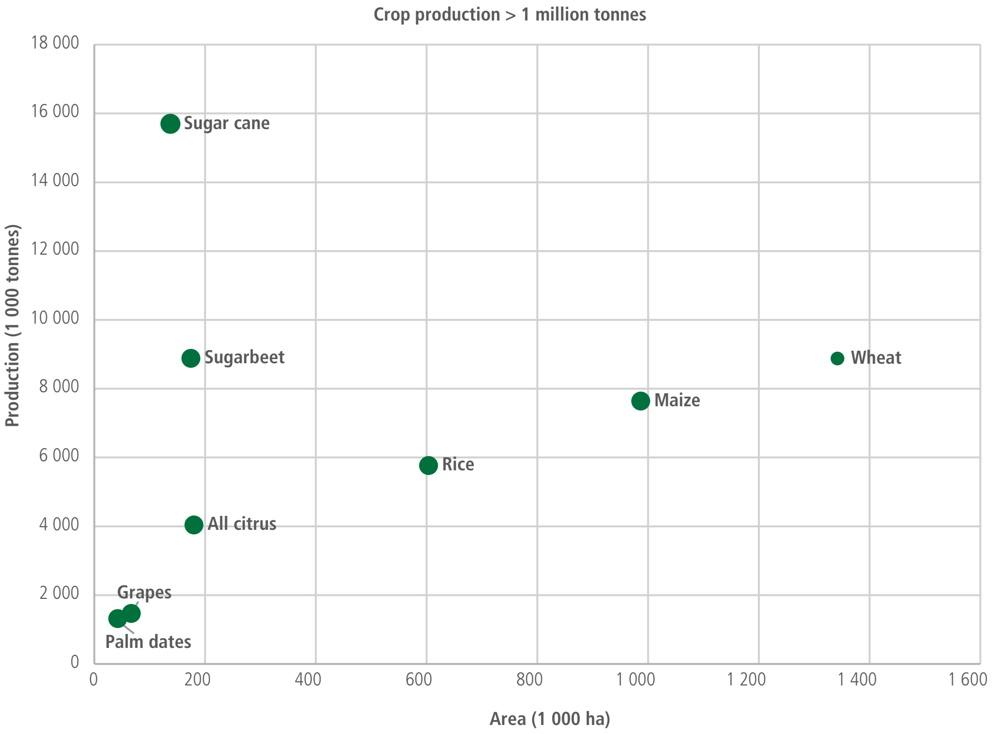
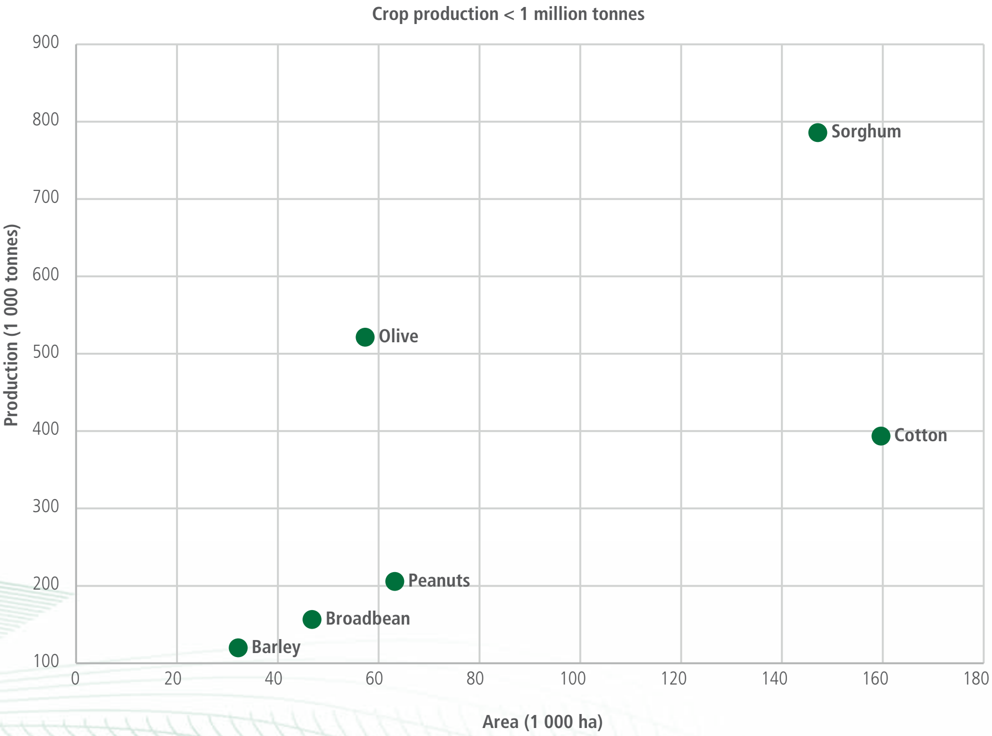


FIGURE 4.

Crops with average production between 100 000 and 1 Mtonnes/year



Availability of crop residues

As already discussed in the methodology section, of the total amount of crop residues produced, only the quantity with no other competitive uses can be considered as available for bioenergy production. In collaboration with the ARC, the following current uses of selected crop residues were identified, along with the respective estimated shares, which allowed for the calculation of the unused amount:

- Left in the field (for soil protection)
- Feed and bedding
- Energy production
- Other uses

Table 3 below illustrates the share of the current uses identified for each crop selected. The shares are the result of judgement by national experts at country level. The same shares were applied to each governorate. The crops from which most of the residues are derived are also highlighted in the table.

The 'not used residues' column in the table provides the final share of residue production potentially available for bioenergy. It should be noted that the 'burnt in the field' practice is not considered as an effective use of residues. Indeed, the related values are already included in the percentage of not used residues.

TABLE 3.

Estimate of current uses of crop residues – Residue availability for bioenergy production (percent)

CROP	RESIDUE TYPE	LEFT IN THE FIELD	USED FOR FEED AND BEDDING	USED FOR ENERGY PRODUCTION	OTHER USES	NOT USED RESIDUES	BURNT IN THE FIELD
Cereals							
Barley	straw	20	80	0	0	0	0
Maize (w+y)	stalk	4	40	10	10	36	0
Rice	straw	7	20	36	3	34	4
Sorghum	stalk	5	95	0	0	0	0
Wheat	straw	10	83	0	7	0	0
Oilseeds							
Soybean	haulm	2	98	0	0	0	0
Peanut	haulm	10	90	0	0	0	0
Sesame	stalk	5	0	40	5	50	0
Sunflower	stalk	5	0	40	5	50	0
Sugar crops							
Sugar cane	bagasse	**5**	**2**	**65**	**5**	**23**	3
Sugar beet	haulm	**5**	**70**	**0**	**5**	**20**	0

CROP	RESIDUE TYPE	LEFT IN THE FIELD	USED FOR FEED AND BEDDING	USED FOR ENERGY PRODUCTION	OTHER USES	NOT USED RESIDUES	BURNT IN THE FIELD
Fruit trees							
All citrus	pruning	25	0	55	0	20	0
Palm date prunings	pruning	5	0	60	20	15	0
Grapes prunings	prunings	10	0	40	25	25	0
Olive prunings	prunings	0	0	50	10	30	0
Pulses							
Broad beans	straw	8	90	0	2	0	0
Lentils	straw	20	70	0	10	0	0
Fibres							
Cotton	stalk	7	0	10	3	80	0
Flax	straw	10	0	0	80	10	0

Results

Production of crop residues

The crop residue production data, which resulted from combining the cultivated area and the residue production rate, confirmed that 75 percent of the country's crops with the highest production contribute to 86 percent of residue production, or 25 563 million tonnes per year. These crops are: wheat, maize and rice for cereals, sugar cane and sugar beet for sugar crops, and all citrus for fruit trees. Average crop and residue production for the full list of crops selected are compared, at national level, in the table below.

TABLE 4.

Average crop and residue production 2011–2013

CROP	TONNES
Sugar cane	15 698 777
Sugar beet	8 886 355
Wheat	8 875 418
Maize	7 642 238
Rice	5 773 012
Citrus & orange	4 039 376
Grapes	1 378 094
Palm dates	1 373 570
Sorghum	785 968
Olive	521 505

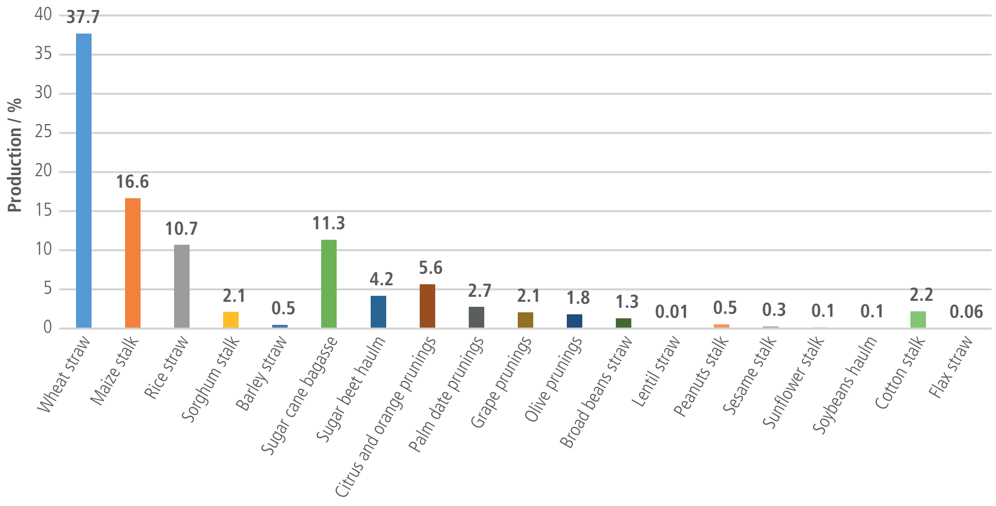
CROP RESIDUES	TONNES
Wheat straw	11 185 147
Maize stalk	4 933 361
Sugar cane bagasse	3 366 092
Rice straw	3 163 112
Citrus & Orange pruning	1 669 249
Sugar beet haulm	1 246 318
Palm dates prunings'	813 908
Cotton stalk	646 117
Sorghum stalk	623 521
Grapes prunings'	619 379

CROP	TONNES	CROP RESIDUES	TONNES
Cotton	393 608	Olive prunings’	532 164
Peanuts	205 595	Broad beans straw	391 770
Broad beans	156 941	Peanuts haulm	153 471
Barley	119 975	Barley straw	145 594
Sesame	35 812	Sesame stalk	90 773
Flax	33 745	Sunflower stalk	39 907
Soybeans	29 607	Soybeans haulm	23 373
Sunflower	19 382	Flax straw	17 363
Lentil	1 085	Lentil straw	1 585
Total	55 970 063	Total	29 662 201

In the category level, the result of the study highlights that of the total residue production of 29 662 million tonnes per year, most of the residues derive from cereals (67.6 percent), in particular wheat, maize and rice (Figure 5). Wheat straw has the largest share (37.7 percent), followed by maize stalk (16.6 percent) and rice straw (10.7 percent). Among the sugar crops, a significant contribution comes from sugar cane bagasse, accounting for 11.3 percent of total national residue production, while a much smaller one is made by sugar beet haulm, which accounts for 4.2 percent of residues. Fruit tree prunings contribute 12.3 percent to national residue production, with citrus and orange prunings playing the most important role within the category (45.9 percent). Very little contribution is made by the remaining crop categories. Among the fibre crops, it is worth mentioning cotton stalk, with a share of 2.2 percent.

FIGURE 5.

Shares of residue production by crop (percent)



The analysis of residue production at subnational level reveals that some governorates are visibly more productive than others, and some crop residues prevail over others, according to their geographical and agroclimatic characteristics. In Figure 6, five groups can be recognized that include governorates with a substantial homogeneity in residue composition and/or amount of production. The chart shows that Behera is the governorate with the highest residue production in the country, with 4 700 million tonnes per year, in which wheat, all citrus, maize and rice are the main sources of residues. It is important to highlight that most crop residues in this governorate originate in Noubaria, an agricultural zone reclaimed from the desert.

Among the most productive governorates, Sharkia, Dakahlia and Kafr–El Sheikh should also be mentioned, with more than 2 million tonnes of residues each, contributing 26.9 percent of national production with 3 142, 2 542 and 2 298 Mtonnes/year respectively. Crop residue composition in this group is similar to that of the previous one, with a prevalence of wheat, rice, maize and sugar beet residues.

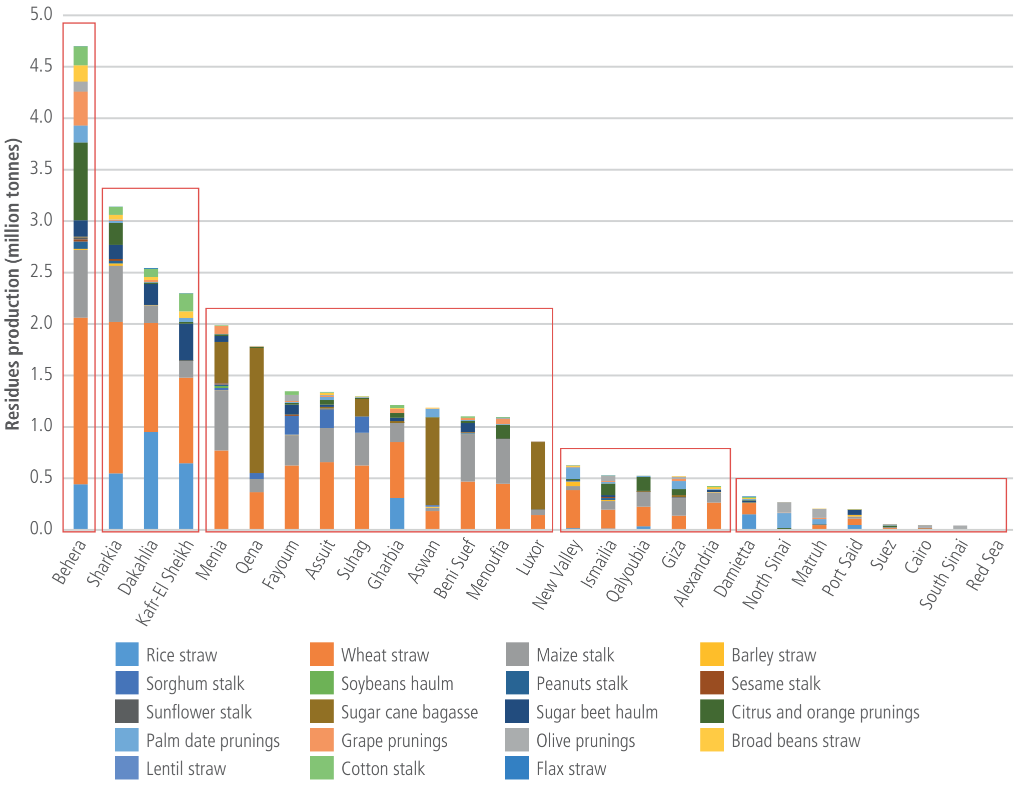
Almost half the total quantity of residues produced (44.5 percent) is distributed among ten governorates: Menia, Qena, Fayoum, Assuit, Suhag, Gharbia, Aswan, Beni, Suef, Menoufia and Luxor. In this group, residues vary from 860 to 1 998 thousand tonnes per year/governorate, and are mainly composed of the following crop residues: wheat straw, sugar cane bagasse, maize and sorghum stalks.

The fourth group includes New Valley, Ismailia, Qalyoubia, Giza and Alexandria, and provides 8.8 percent of national residue production, or 2 622 Mtonnes/year from wheat, maize, citrus and palm dates.

The last group includes the remaining governorates: Damietta, North Sinai, Matruth, Port Said, Suez, Cairo, South Sinai and Red Sea. Crop residue production reaches 1 145 million tonnes per year (3.9 percent), with olive and palm dates as the main sources.

FIGURE 6.

Residue production average by governorate (percentages indicate the share of residues over the national total)

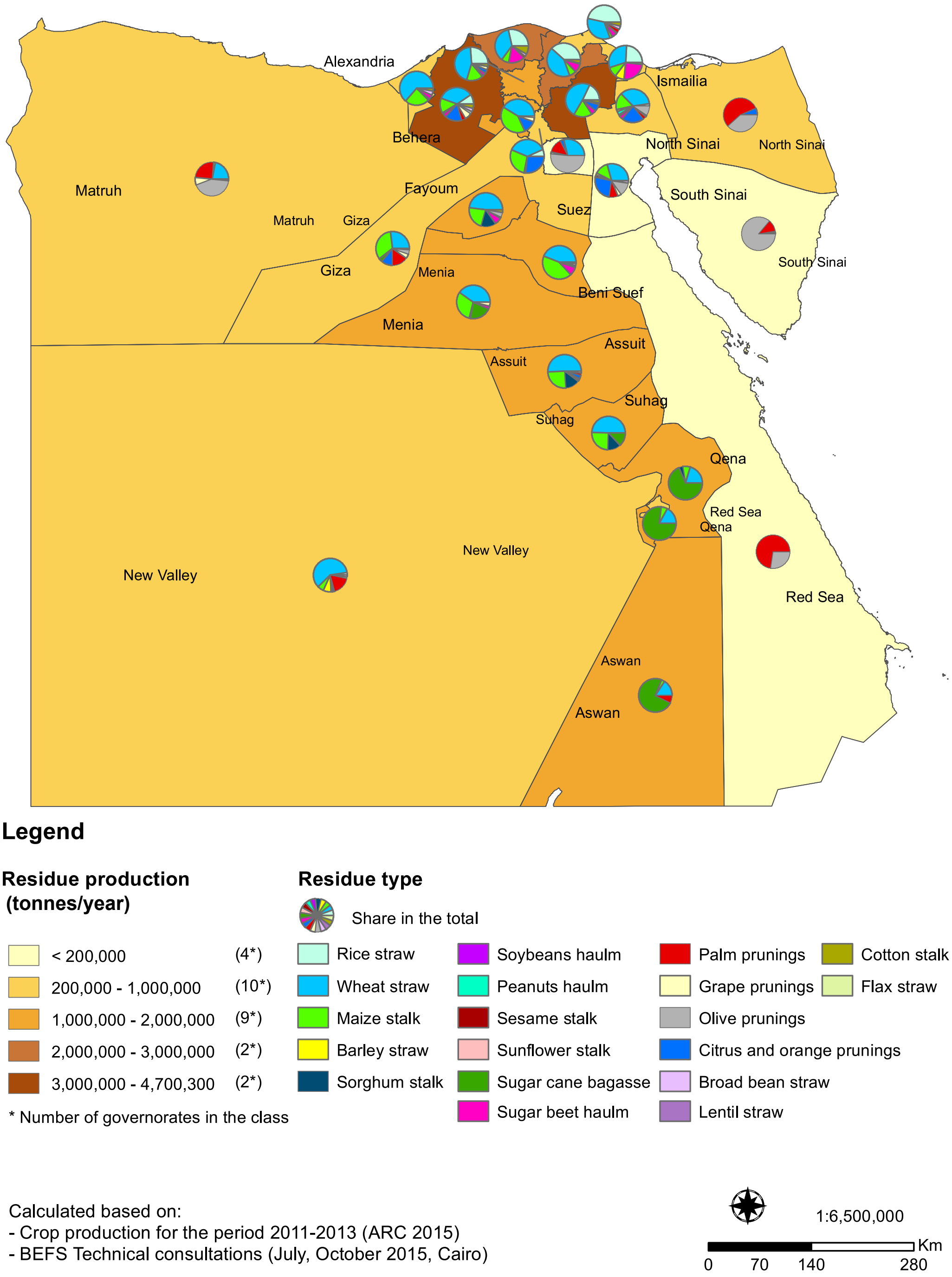


The combination of residue production (size) and residue type (share) in Egypt is also displayed in the geographic map below (Figure 7). Different colours are used to represent each governorate with the corresponding production class as given in the previous figure, while the pie charts indicate the composition of the relative residues. The classification method is based on the natural breaks (Jenks) algorithm, which identifies break points by picking the class breaks that best group similar values and maximize the differences between classes.

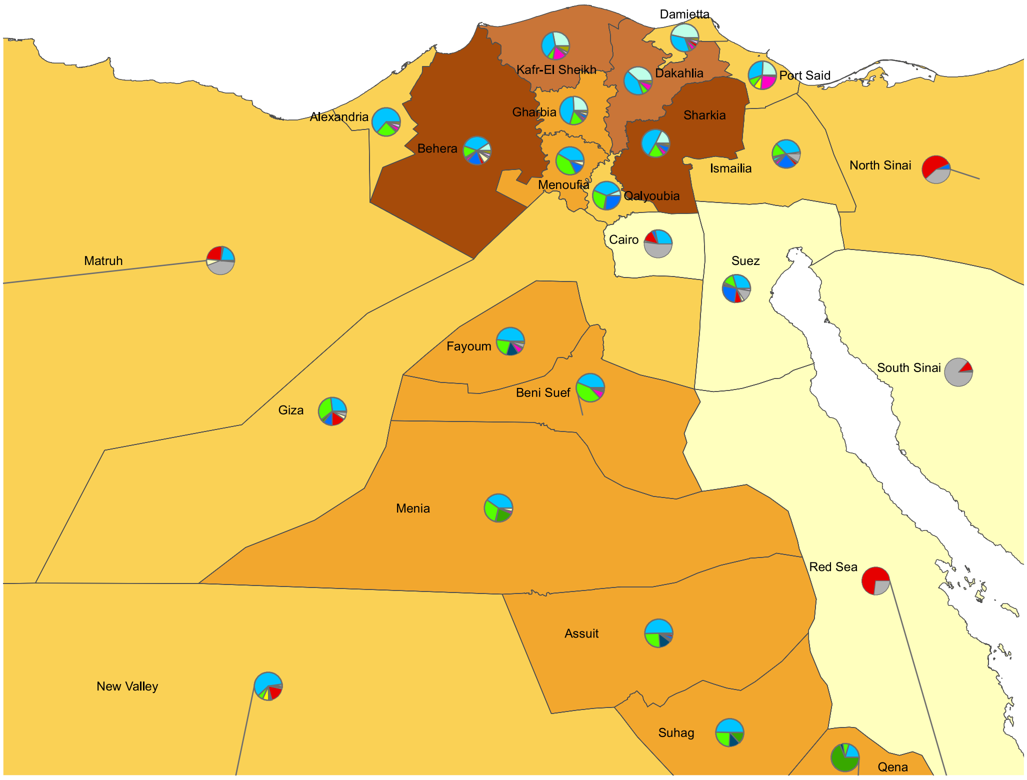
To simplify the analysis result, at national scale, total residue production can be represented by just three levels: high, medium and low. The geographical distribution of total crop residues shows that high production is mainly concentrated in the Middle Delta region (displayed with the darker brown areas on the map), providing most of the wheat, rice, maize and citrus residues in the country. Medium production is located in Middle and Upper Egypt, along the Nile basin, where sugar cane bagasse and wheat straw are mainly represented. Finally, lower production, displayed with the lighter colours on the map, is distributed among the governorates further away from the Nile and along the coast, in which production of wheat, olive and palm date residues prevails.

FIGURE 7.

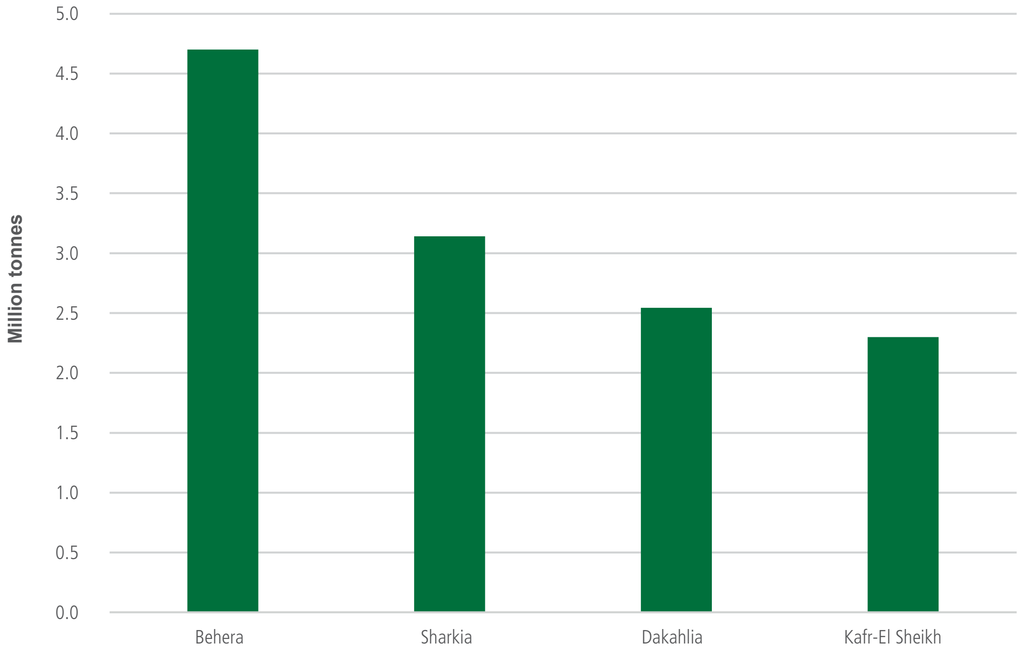
Map of crop residue production in Egypt



Calculated based on:
- Crop production for the period 2011-2013 (ARC 2015)
- BEFS Technical consultations (July, October 2015, Cairo)



Top four provinces with most production of residues



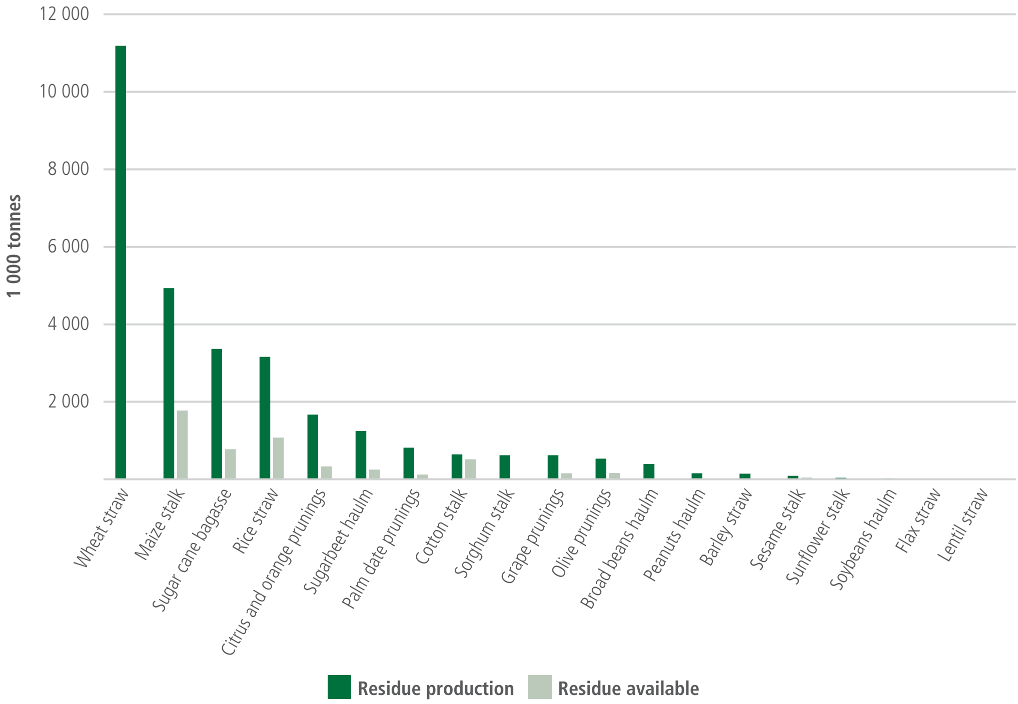
Availability of crop residues

From Table 3, it is clear that among the cereals, only maize and rice may be a source of residues for bioenergy production. Wheat, barley and sorghum residues are already completely utilized, mostly for animal feed and bedding. The same is true for other categories: in the case of soybean, peanut, broad bean and lentil, competition for current uses is very high. Among oilseeds, both sesame and sunflower could each provide 50 percent of their total residues for bioenergy, whereas in the sugar crops category, sugar cane and sugar beet could contribute 23 percent and 20 percent of residues respectively. Fruit trees also appear to have potential for bioenergy production, with residues being available at levels of 30 percent for olives, 25 percent for grapes and 15 percent for palm dates. In the same category, the pruning of citrus branches represents the most significant source of residues for bioenergy, as demonstrated by combining its residue production level from Table 4 with the share of availability (20 percent). While residues from pulses did not demonstrate any potential for bioenergy due to their alternative usage, residues from fibres, especially cotton, were found to be largely unexploited and with great potential in the residues available sector (80 percent).

Figure 8 below illustrates crop residue production and availability, compared at national level for the full list of crops identified.

FIGURE 8.

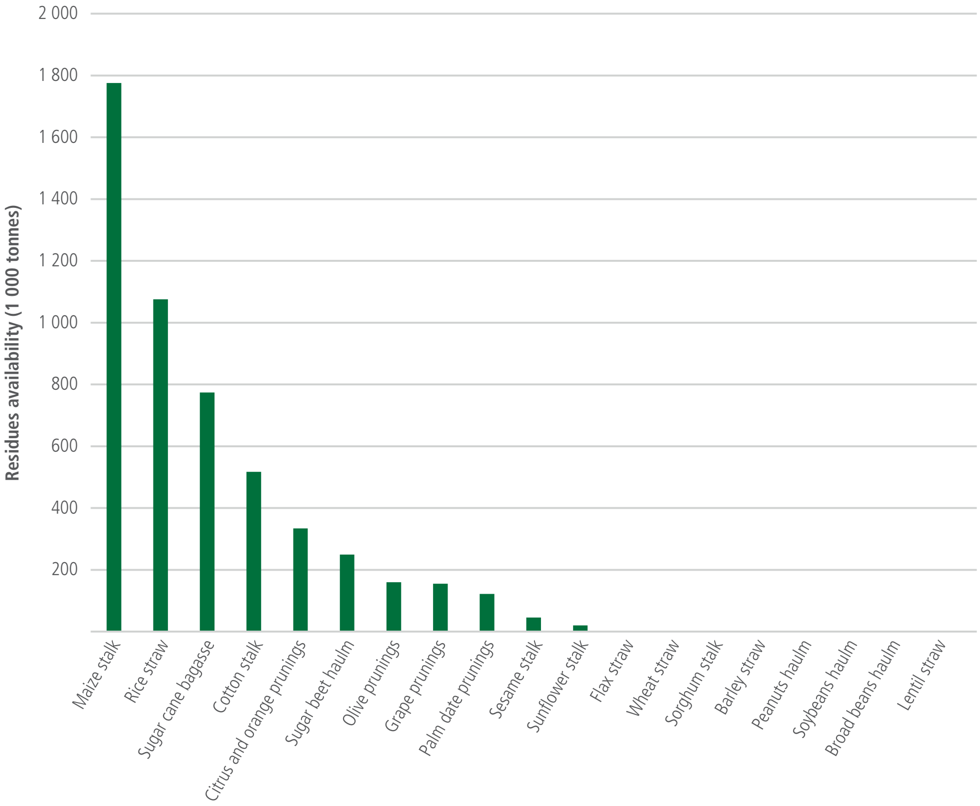
Residue production and residue availability for bioenergy purpose at national level



Based on the total amount of residues produced and on the percentage of availability of each crop (Table 3 and Table 4), Figure 9 shows the final result of the data analysis performed, giving the absolute amount of crop residues available at national level. The figure illustrates, both as a table and chart, the crops that provide the highest amount of residues available for bioenergy at national level. These crops are cereals, in particular maize and rice. Additionally, other high–ranking crops include sugar cane among the sugar crops, and cotton among fibres. The fruit category also shows a consistent degree of availability of residues, with citrus and orange in the highest ranking. In the oil category, either a few or no residues are available for bioenergy production.

FIGURE 9.

Residue availability for bioenergy purpose at national level



CROP RESIDUES	TONNES
Maize stalk	1 776 010
Rice straw	1 075 458
Sugar cane bagasse	774 201
Cotton stalk	516 893
Citrus & orange pruning	333 850
Sugarbeet haulm	249 264
Olive pruning	159 649
Grapes pruning	154 845
Palm dates pruning	122 086
Sesame stalk	45 387
Sunflower stalk	19 953
Flax straw	1 736

CROP RESIDUES	TONNES
Wheat straw	0
Sorghum straw	0
Barley straw	0
Peanuts haulm	0
Soybeans haulm	0
Borad beans haulm	0
Lentil straw	0
Total	**5 229 332**

The analysis of residues available for bioenergy at subnational level reveals the same spatial distribution noted for residue production, with Behera, Sharkia, Dakahlia and Kafr–El Sheikh ranking at the top, with 46 percent of national production. These governorates show a range of some 400 000 to 800 000 tonnes of residues unused per year, mainly from maize, rice, all citrus, grapes and cotton (Figure 10). A significant quantity of residues available is also provided by the governorates of Menia and Qena (12.9 percent), with more than 300 000 tonnes per year in each case. These residues are almost entirely derived from maize and sugar cane. The same crops also produced most of the 1 500 million tonnes of residues available in Gharbia, Aswan, BeniSuef, Manoufia, Fayoum, Luxor, Suhag and Assuit, which each contribute variable amounts, ranging from 158 000 to 228 000 tonnes/year, accounting for 29.4 percent of total production in the country. Finally, the remaining governorates contribute a small amount of residues, ranging from 750 to 100 000 tonnes per year, mainly derived from maize, rice, citrus, palm dates and olives.

FIGURE 10.

Residue availability for bioenergy purpose at governorate level

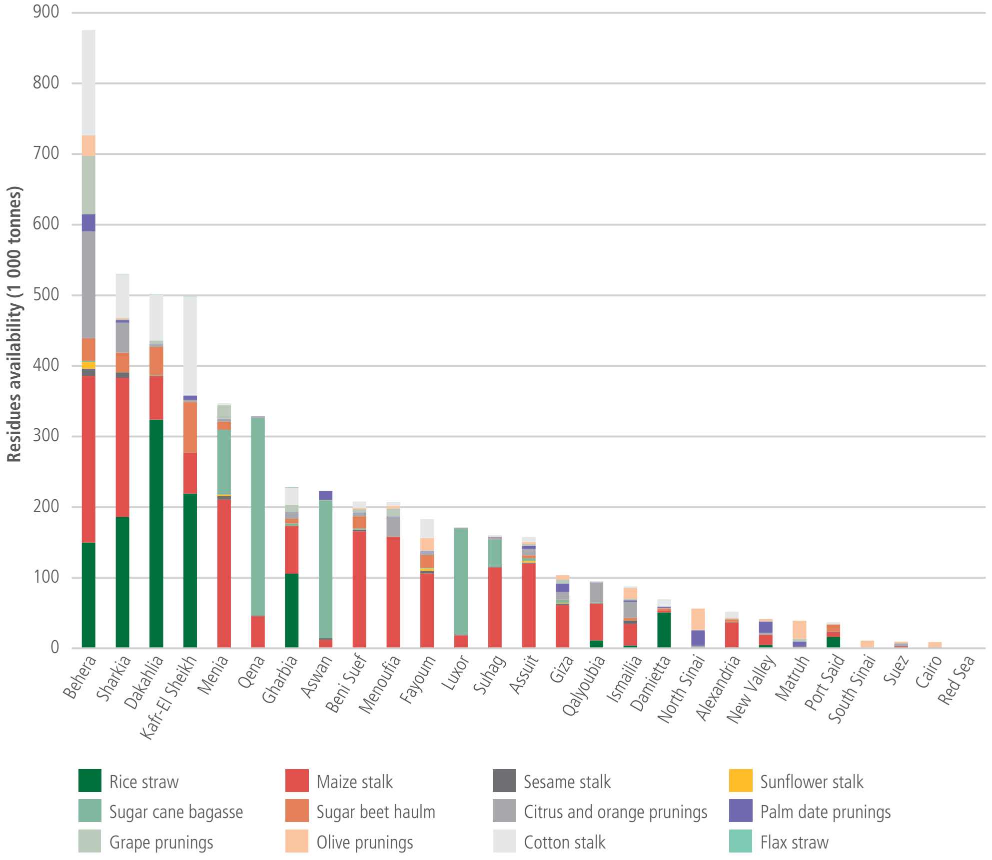
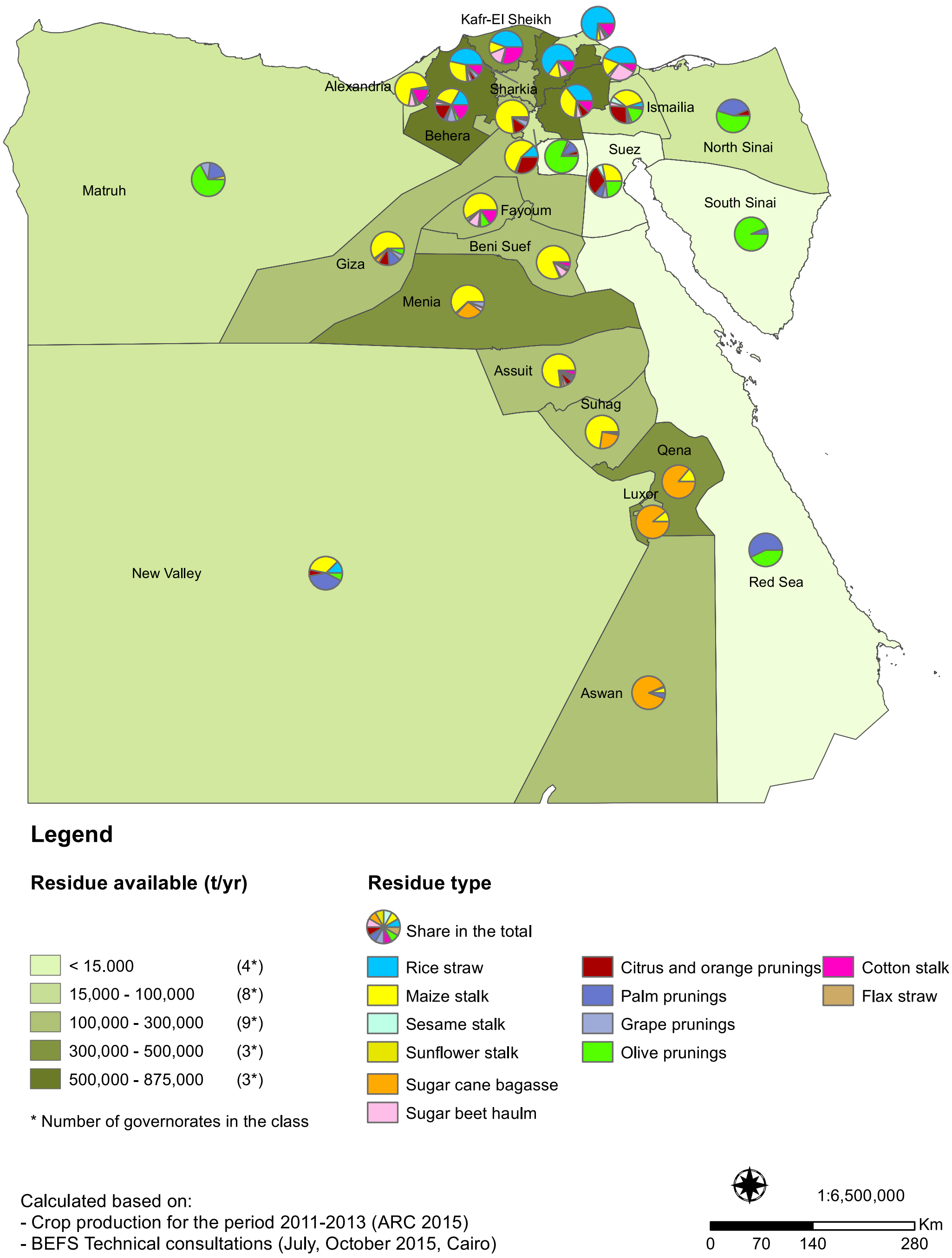


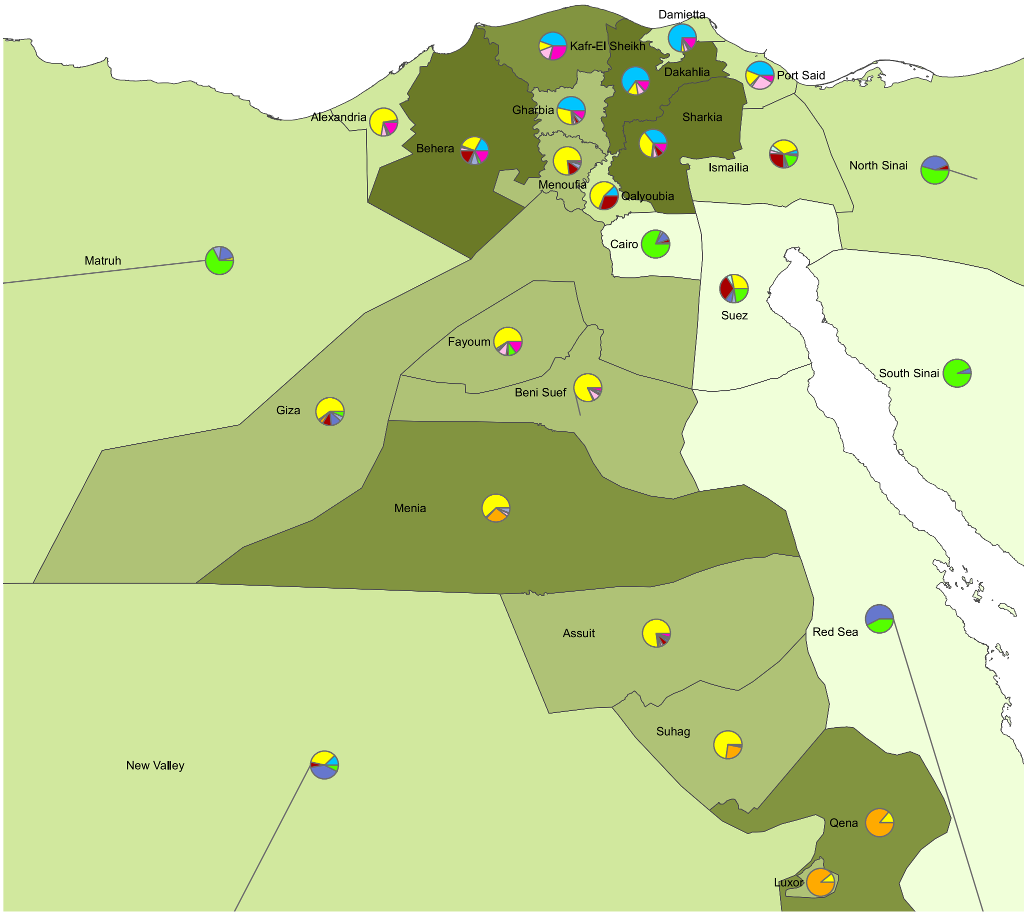
Figure 11 shows the geographical distribution of the availability of these residues in Egypt, as well as the distribution of residue types across governorates. Similar to residue production, high rates of residue availability (indicated by darker areas) is mainly concentrated in the Middle Delta region. Medium rates are located in Middle and Upper Egypt, along the Nile basin, while low rates are distributed among governorates further away from the Nile and along the coast.

FIGURE 11.

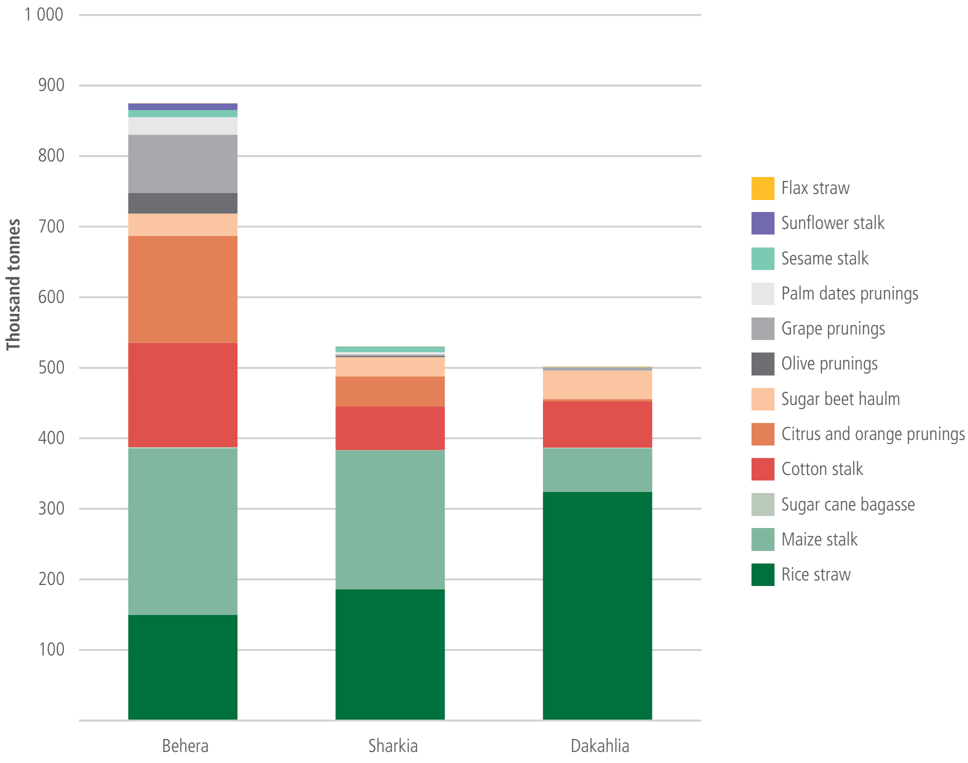
Map of crop residue availability in Egypt



Calculated based on:
- Crop production for the period 2011-2013 (ARC 2015)
- BEFS Technical consultations (July, October 2015, Cairo)



Top 3 governorates with the highest availability



LIVESTOCK RESIDUES

Methodology

Production of livestock residues

The production of livestock residues (i.e. animal manure) represents a theoretical bioenergy potential. The production represents the total amount of manure generated by a certain animal category and does not take into account whether this manure is utilized, or how much and how.

The basic calculation for the production follows the equation below:

$$LV_{res\text{-}tot(i)} = LV_{prod\ (i)} * M_{head}$$

Where:

$LV_{res\text{-}tot(i)}$ [tonnes/year] = Total amount of manure produced by certain animal category per year

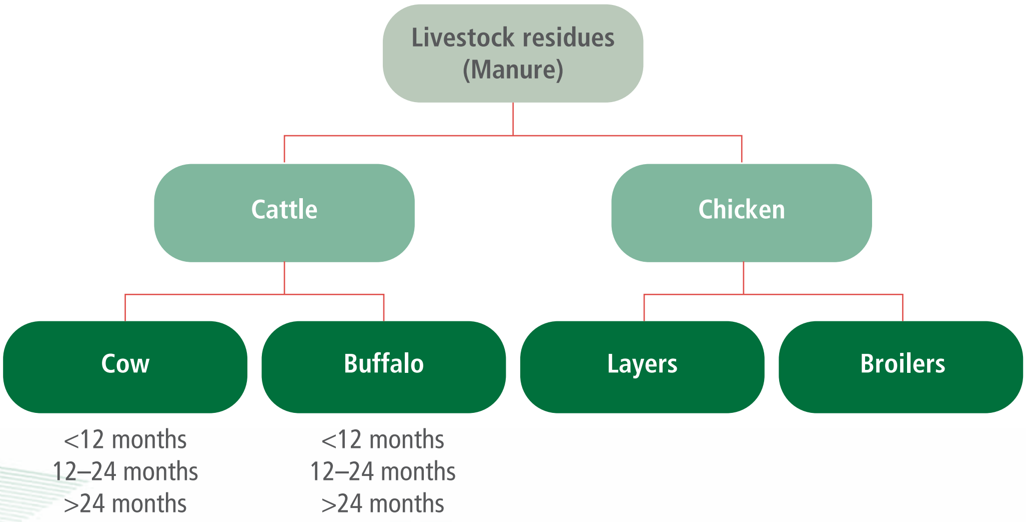
$LV_{prod\ (i)}$ [head/year] = Number of animals within one animal category per year

M_{head} [t/head] = Amount of manure produced per head of each animal category per year

This equation is applied separately for cattle and chicken manure. It is also important to note that further disaggregation of data was performed in order to reflect some other parameters impacting manure excretion. After technical consultations for cattle with the national stakeholders, further division was made based on cattle type and especially age, since the latter corresponds to body weight and therefore excretion rate (the older the animal is, the higher the excretion rate). In regards to chicken, the distinction was made between layers and broilers, due to primarily different management practices. The following figure presents the type of livestock residues assessed in the study.

FIGURE 12.

Livestock residues assessed in the study



Availability of livestock residues

After estimating the production level, the next step is to estimate the availability of livestock residues (i.e. manure). Availability refers to the amount of manure from a certain animal category that could be potentially available for bioenergy production, taking into account all current competing uses. It therefore represents a portion of estimated production and can be referred to as the technical potential. Within this study, by acknowledging current uses, availability assumes no interference with other, already established markets.

Manure is a valuable material that can be used for various purposes (e.g. fertilizer, composting, energy, etc.). At the availability level, it is very important whether or not manure is already being practically utilized and, if so, the amount of manure being used, regardless of the exact purpose.

The basic calculation for the availability follows the equation below:

$$LV_{bioen(i)} = LV_{res\text{-}tot(i)} - LV_{res\text{-}used}$$

Where:

$LV_{bioen(i)}$ [tonnes/year] = Potentially available amount of manure produced by a certain animal category per year

$LV_{res\text{-}tot(i)}$[tonnes/year] = Total amount of manure produced by certain animal category per year

$LV_{res\text{-}used}$[tonnes/year] = Amount of manure from certain animal category already used for other purposes

This equation is applied separately for cattle and chicken manure. As for production, livestock residue availability was also estimated at governorate level, assuming the same shares of current uses for each governorate, due to inaccessibility of governorate specific data.

Data collection

Production of livestock residues

Cattle

In line with the methodological approach, data collected for the estimate of cattle manure production (i.e. theoretical bioenergy potential) were as follows:

- Number of cows and buffalo per age class and per governorate for each year in the period 2011 to 2013
- Manure production per head per day for different cattle age classes

These data, after aggregation, are presented later in the report. Disaggregated data are presented in the Annex.

FIGURE 13.

Number of cattle per subcategory – governorate level (average 2011–2013)

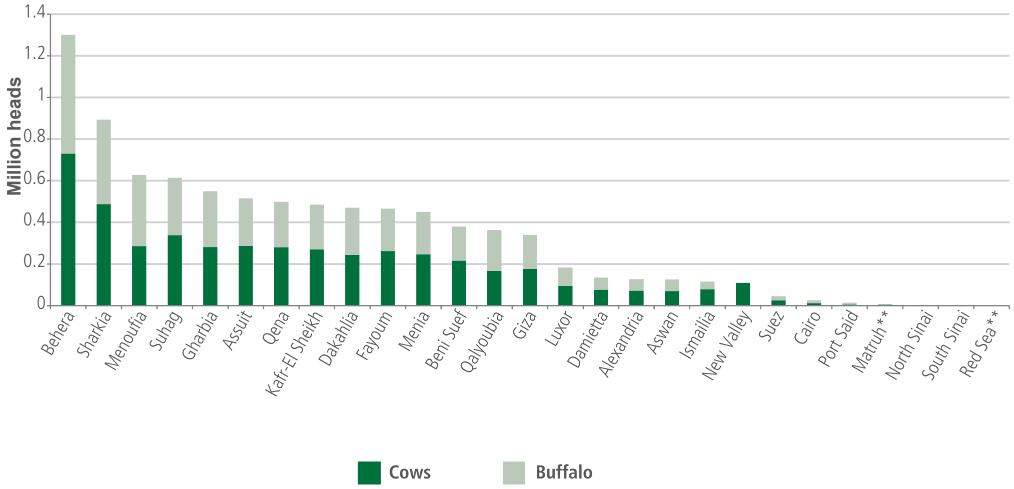
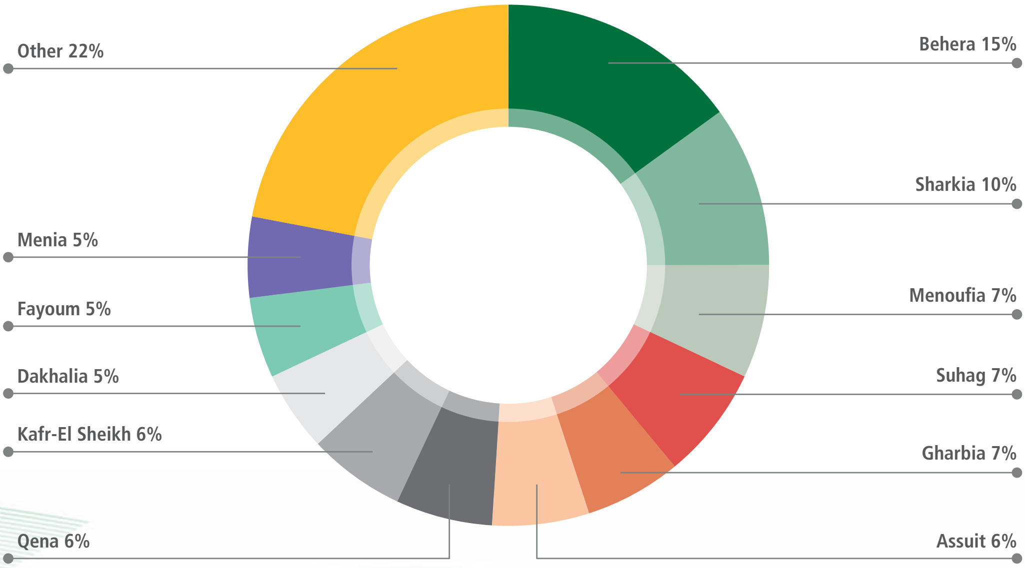


Figure 13 and Figure 14 show that the Behera governorate has the highest number of cattle, followed by Sharkia, Menoufia and Suhag. The respective shares in the total number of cattle are 15 percent, 10 percent, 7 percent and 7 percent. Therefore, more than one–third of the cattle fund in Egypt is located in these 4 governorates. Also, the figures clearly show that a number of governorates have a similar share, implying that the geographical distribution of cattle within Egypt is not highly scattered. This fact is directly connected to the geographical distribution of cattle manure, so should be borne in mind when analysing the results. The full list of shares for each governorate is presented in the Annex.

FIGURE 14.

Share of each governorate in total number of cattle[6]



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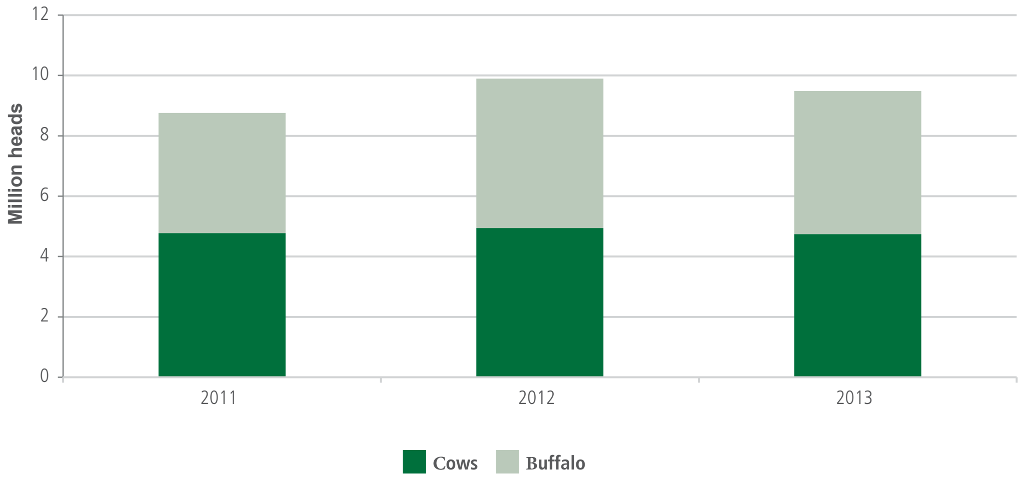
[6] Other' represents governorates whose share is lower than 5 percent of the total number of animals.

Also, the cow/buffalo ratio in the vast majority of governorates is mostly around 1. This means that half the cattle number is represented by cows and half by buffalo.

At national level, on average there are about 8.9 million cattle and this number did not change significantly during the period 2011 to 2013 (Figure 15). The share of cows and buffalo is relatively similar and follows the pattern identified at governorate level.

FIGURE 15.

Number of cattle per subcategory – national level



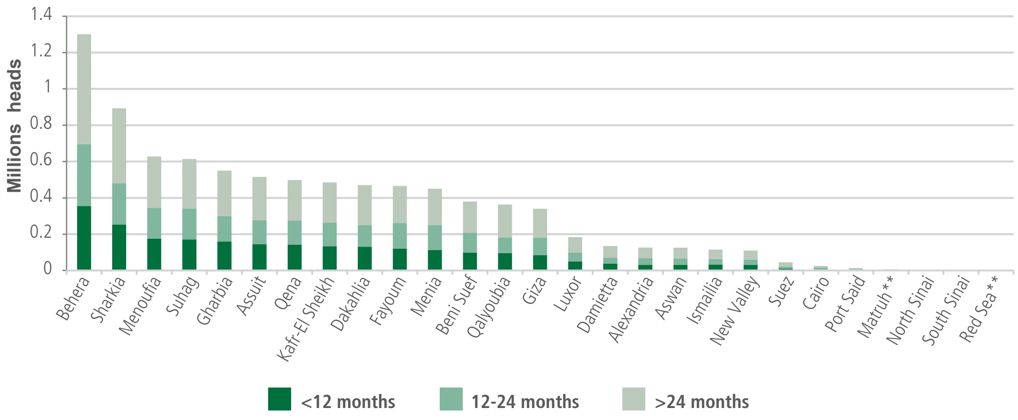
As mentioned in the methodology, one of the criteria for the further division of cattle was the age structure. The structure consists of:

- Cattle younger than 12 months;
- Cattle between 12 and 24 months; and
- Cattle older than 24 months.

The figure below shows the number of each age class per governorate. In practical terms, all governorates show that the highest share of animals are those older than 24 months (around 50 percent of each governorate's total cattle number), while the remaining two age classes make up almost the same share together (around 25 percent each).

FIGURE 16.

Number of cattle per age class – governorate level (average 2011–2013)



At national level, the distribution of age classes follows the conclusion reached at governorate level. On average, cattle older than 24 months make up about 46 percent of the total number, while those in the two groups of 12–24 months, and younger than 12 months, contribute 27 percent each.

FIGURE 17.

Number of cattle per age class – national level)

Again, referring to the methodology, the second most important parameter in estimating manure production is manure production per head, which is highly dependent on body weight and therefore linked to the age class. Daily manure production per head of cattle is presented in the table below.

TABLE 5.

Daily manure production per head – cattle

CATTLE AGE	GROSS WEIGHT	MANURE PRODUCTION	
	kg / head	Percent	kg / head / day
Less than 12 months	51 – 53	6	3.1 – 3.2
			by average 3.15
12–24 months	168 – 177	6–8	11.7 – 12.4
			by average 12.1
More than 24 months	494 – 525	6–8	34.5 – 36.7
			by average 35.6

Source: ARC

In order to follow the methodological approach, which aims not to overestimate the potential, a conservative positon was applied here. This involved taking an average body weight and minimum manure excretion per body weight of 6 percent.

Layers and broilers

Data collected and corresponding sources for estimation of chicken manure production (i.e. theoretical bioenergy potential) were as follows:

- Number of broilers (poultry census 2008 and 2012 – FAO Egypt)
- Number of layers (poultry census 2008 and 2012 – FAO Egypt)
- Manure production per head per day for broilers and layers (ARC)

After aggregation, these data are presented later in the report. Disaggregated data are presented in the Annex.

At national level, there is an average of some 625 880 heads of chicken, with broilers making up the largest share at 96 percent. Figure 18 shows the number of chickens per subcategory (layers and broilers) for each governorate. In terms of total number of chickens, the top three governorates are Sharkia, Minya and Behera, which account for 18 percent, 17 percent and 12 percent respectively. Hence, almost half the total number of chickens is found in these three governorates.

FIGURE 18.

Number of chickens per subcategory – governorate level (average poultry census 2008 and 2012)

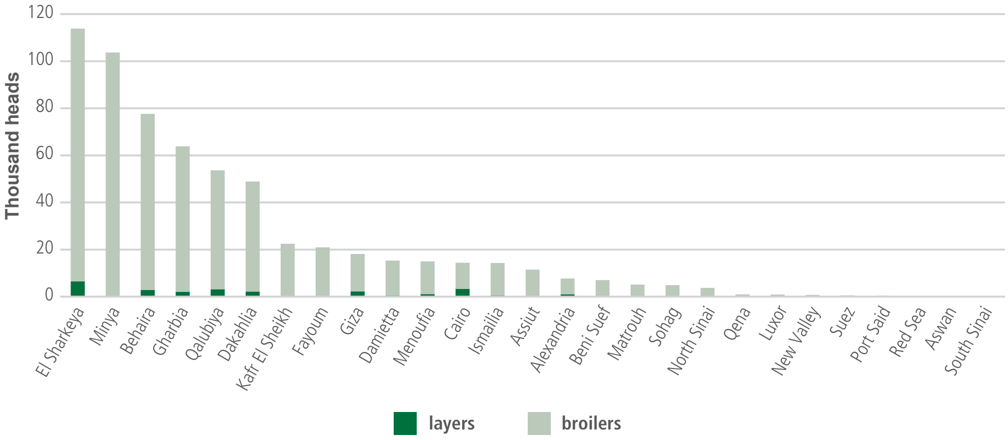
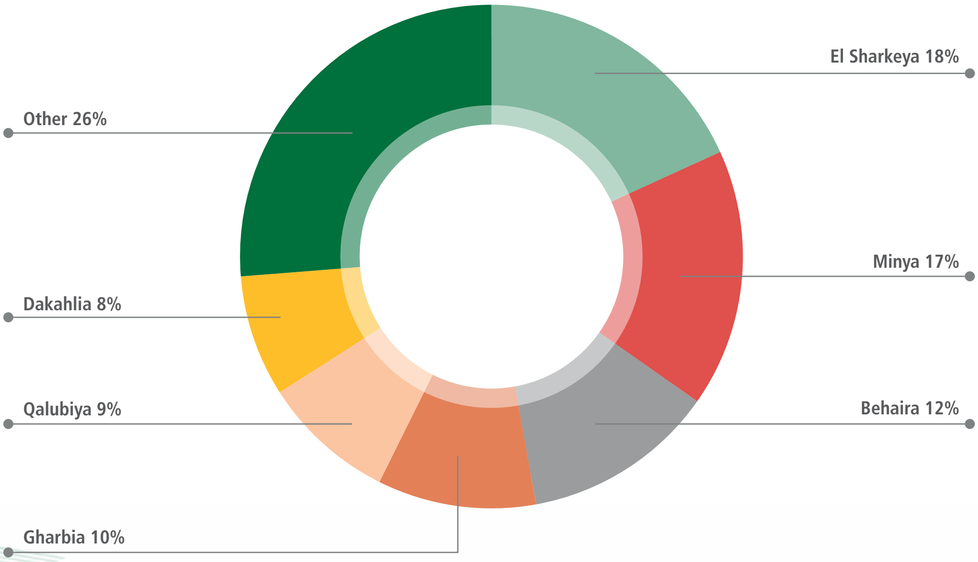


Figure 19 shows the respective shares of each governorate in the total number of chickens in the country. The information presented indicates that more than 70 percent of the total number of chickens is located in 6 of the 27 governorates. As in the case of cattle, this implies that the geographical distribution of chickens within Egypt is not widely scattered. Since this factor is directly linked to the geographical distribution of chicken manure, it should be borne in mind when analysing the results. The full list of shares for each governorate is presented in the Annex.

FIGURE 19.

Share of each governorate in the total number of chickens[7]



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[7] Other' represents governorates whose share is lower than 5 percent of the total number of layers.

With regards to numbers of layers, there are around 27 000 heads in Egypt. The top governorate in this respect is Sharkia, which accounts for 24 percent of all layers. This is followed by the governorates of Cairo (12 percent), Qalubiya (12 percent), Behera (10 percent), Giza (8 percent), Dakahlia (8 percent) and Gharbia (8 percent). Therefore, more than 80 percent of the total number of layers is located in 7 of Egypt's 27 governorates. The conclusion reached for chickens is also valid here – layers are not widely scattered throughout Egypt and this has a direct impact on the geographical distribution of layer manure. Figure 20 shows the number of layers per governorate, while Figure 21 shows the share of each governorate in the total number of layers. The full list of shares for each governorate is presented in the Annex.

FIGURE 20.

Number of layers – governorate level (average poultry census 2008 and 2012)

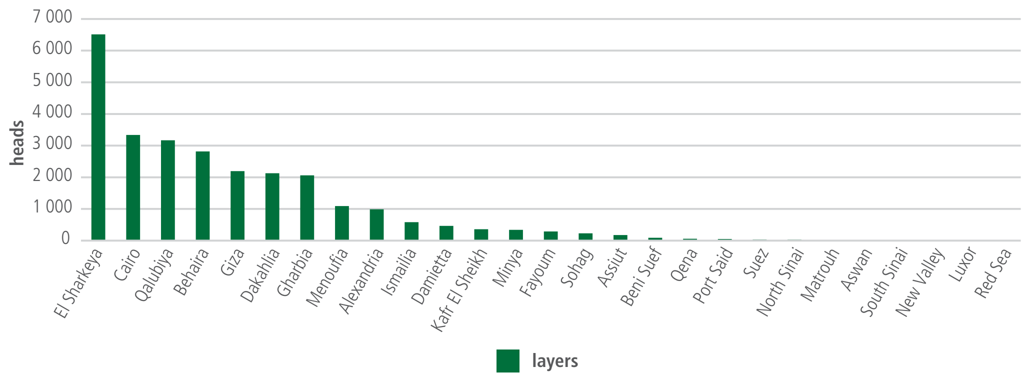
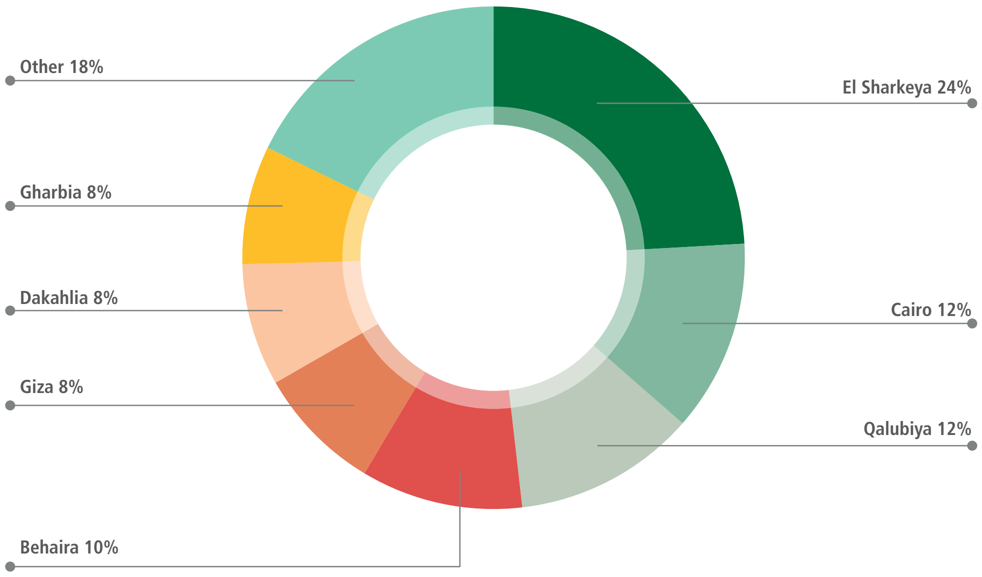


FIGURE 21.

Share of each governorate in total number of layers[8]



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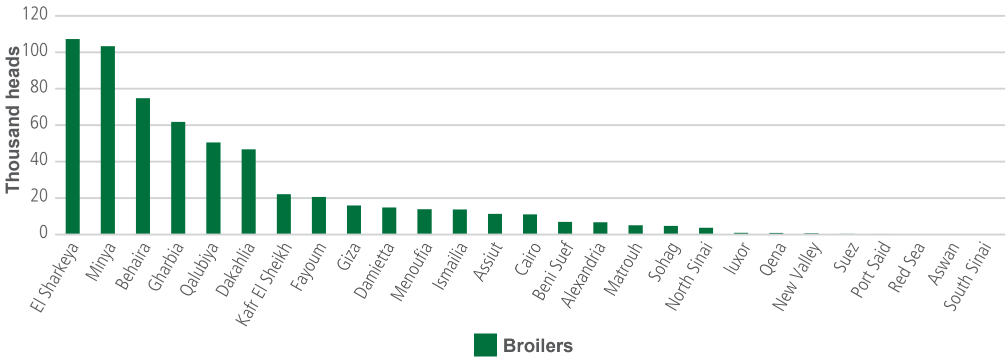
[8] Other' represents governorates whose share is lower than 5 percent of the total number of broilers.

In Egypt, there are around 599 000 broilers. The top two governorates in terms of broiler number are Sharkia and Minya, with respective shares of 18 percent and 17 percent. Therefore, one–third of the broiler population is situated in these two governorates. Sharkia and Minya are followed by Behera (13 percent), Gharbia (10 percent), Qalubiya (8 percent) and Dakahlia (8 percent). Altogether, these governorates make up almost 75 percent of Egypt's total broiler population. The fact that the vast majority of the broiler population is located in 6 of the 27 governorates, as in the case of layers, is an indication that broilers are not widely scattered throughout Egypt. This has a direct impact on the geographical distribution of broiler manure. Figure 22 shows the number of broilers per governorate, while Figure 23 shows the share of each governorate in the total number of broilers.

FIGURE 22.

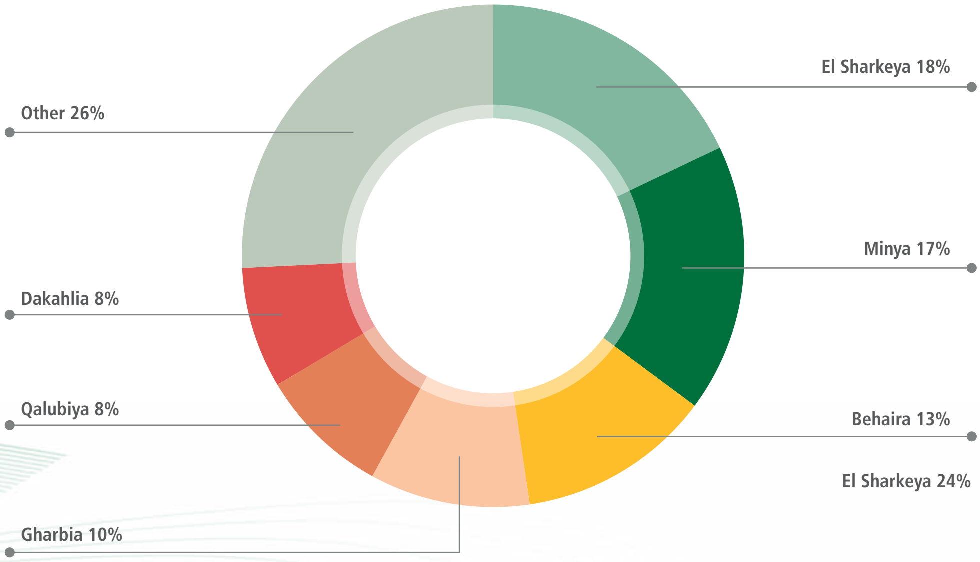
Number of broilers – governorate level (average poultry census 2008 and 2012)



The full list of shares for each governorate is presented in the Annex. The statistics at governorate level already indicate distribution of the bioenergy potential.

FIGURE 23.

Share of each governorate in total number of broilers[9]



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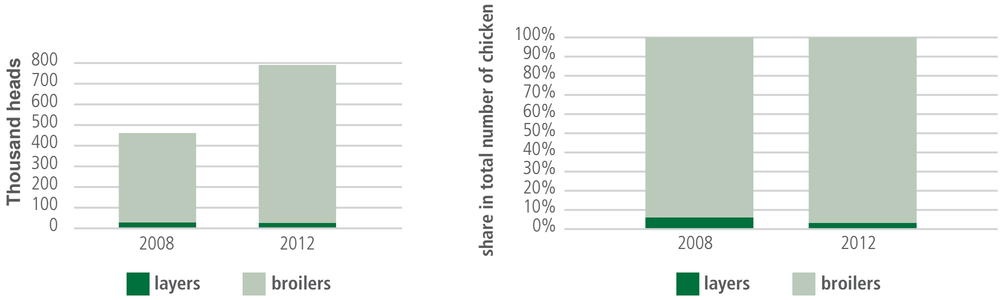
[9] Other' represents governorates whose share is lower than 5 percent of the total number of broilers.

Figure 24 shows the average chicken number by subcategory at national level for the years 2008 and 2012. In 2008, there were about 461 300 chickens, with layers accounting for a very small share of just 6 percent and broilers making up most of the total number of chickens at 94 percent. The same conclusion can be made for 2012 when, out of 790 500 chickens, layers made up just 3 percent of the total, with broilers accounting for the remaining 97 percent. A comparison of statistics between 2008 and 2012 reveals that the total number of chickens rose by 71 percent, mainly due to a high increase in the number of broilers (77 percent increase). Both in absolute and relative terms, layer numbers declined between these years.

FIGURE 24.

Number of chickens per subcategory – national level (average poultry census 2008 and 2012)



After the number of heads/birds, the second most important parameter in estimating manure production is manure production per head. In the case of chickens, this is highly dependent on rearing practices, which can be differentiated between layers and broilers, given their purpose (layers for eggs, broilers for meat). Manure production per bird is presented in the table below as a result of technical consultations with national experts.

TABLE 6.

Daily manure production per head – chickens

CHICKEN CATEGORY	MANURE PRODUCTION
	kg / head / day
Layers	0.026
Broilers	0.028

Source: ARC

Availability of livestock residues

Cattle

After estimating total manure production, its availability depends solely on one factor, and that is whether or not the cattle manure is already used and if so, how much. Following technical consultations, the current uses and corresponding shares are presented in the table below.

TABLE 7.

Current uses of cattle manure

APPLICATION	CATTLE MANURE
Composting	15 – 20 percent
Farm yard manure (FYM), direct fertilizer	20 – 30 percent
Home energy	10 – 20 percent
Biogas production	3 – 5 percent
Total used	48 – 75 percent
Not used	52 – 25 percent

Source: ARC

In the light of these figures, it is estimated that 25 to 52 percent of cattle manure that is not currently used could be potentially available for future bioenergy projects. Again, following the methodological approach that seeks to avoid overestimating the potential, a conservative 25 percent availability is assumed.

Layers and broilers

As in the case of cattle manure, following technical consultations with ARC, current uses and corresponding shares applicable for chicken manure are presented in the table below. No distinction was made between broilers and layers, due to lack of availability of such specific information.

TABLE 8.

Current uses of chicken manure

APPLICATION	CHICKEN MANURE
Composting	20 – 25 percent
Farm yard manure (FYM), direct fertilizer	75 – 80 percent
Home energy	---
Biogas production	---
Total used	95 – 100 percent
Not used	0 – 5 percent

Source: ARC

In the light of these figures, it is estimated that 0–5 percent of the total volume of chicken manure could potentially be available for future bioenergy projects. Again, a conservative approach was applied, which assumes no availability (0 percent) of chicken manure for new bioenergy projects.

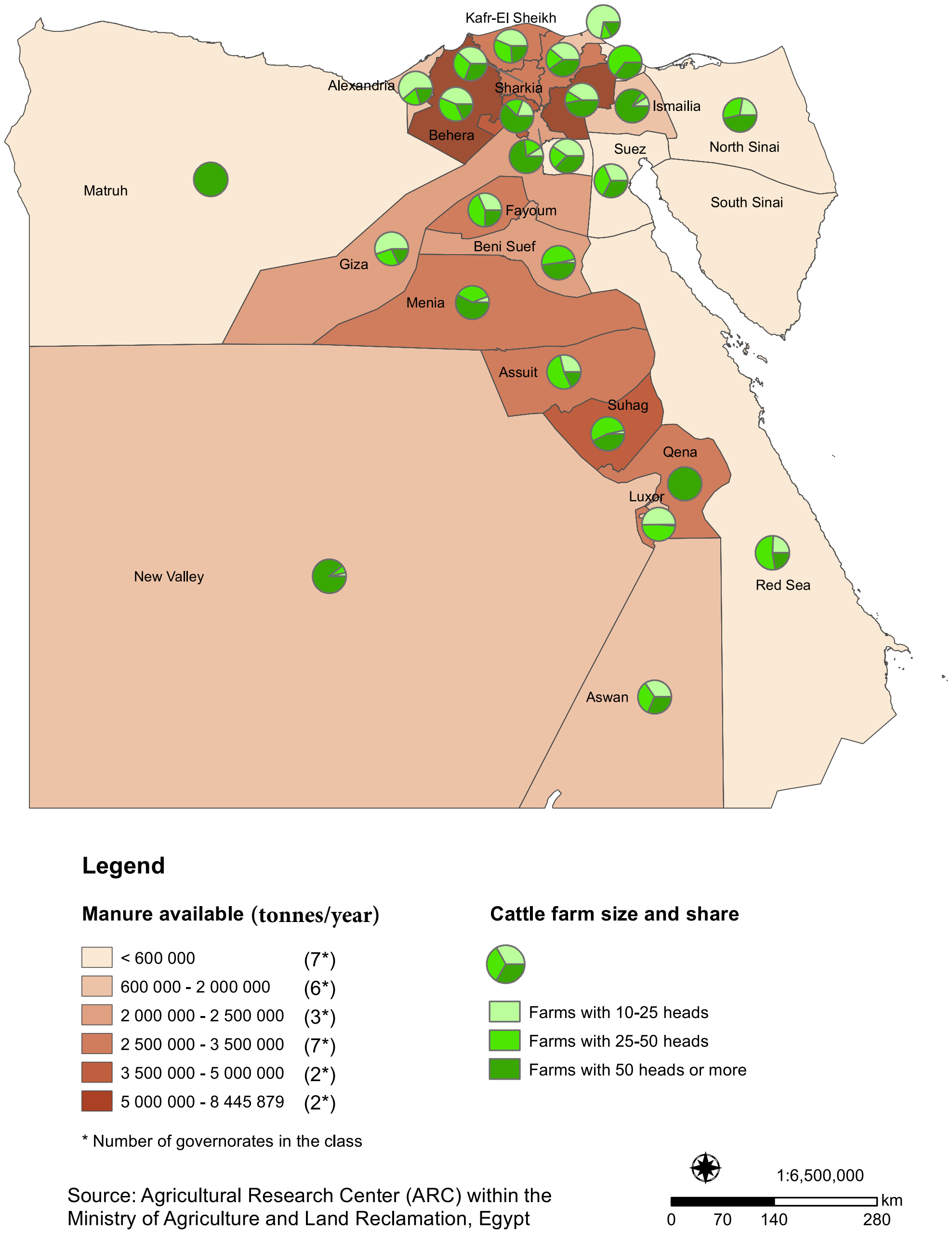
Production of livestock residues

Cattle

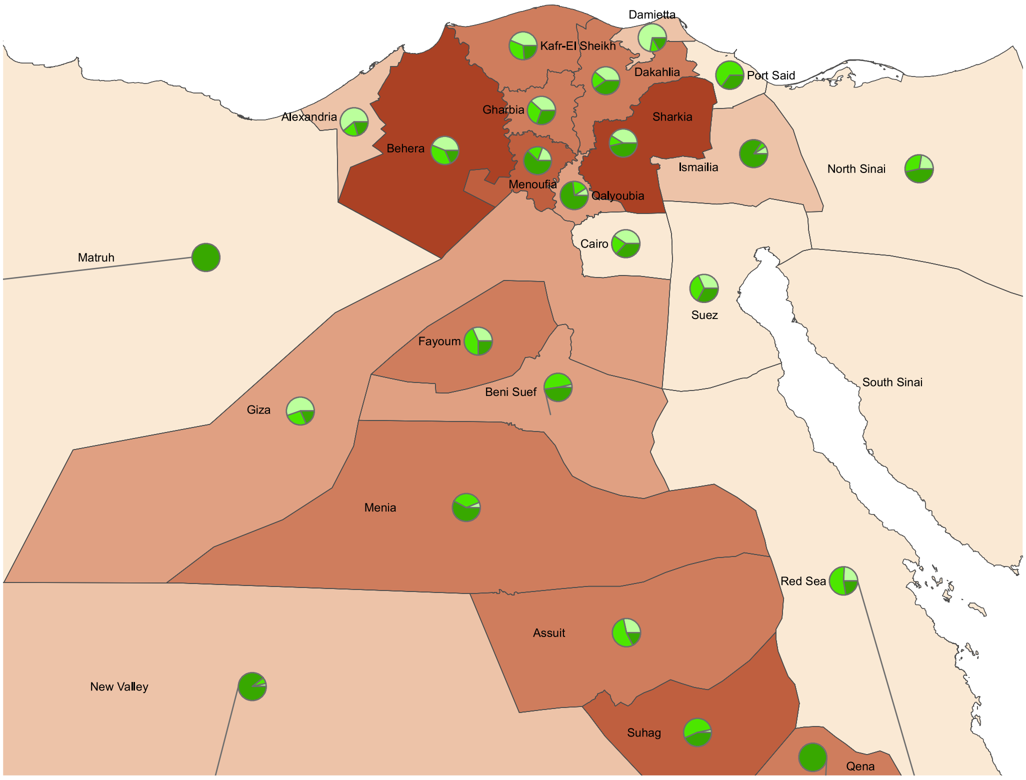
Figure 31 shows a map of the geographical distribution of cattle manure production in Egypt, as well as distribution of farms across governorates. The darker brown areas represent higher manure production, while the lighter shades of brown represent a lower production rate. The map also shows the distribution of farms in the form of pie charts, varying from smallholdings (farms with 10–25 heads), to medium–sized farms (25–50 heads) to large–scale farms (≥ 50 heads). The farm structure (size and share) is important when assessing accessibility, and this will be explained later in the study.

FIGURE 25.

Map of total production of cattle manure – governorate level (below spotlight on Middle Delta region)



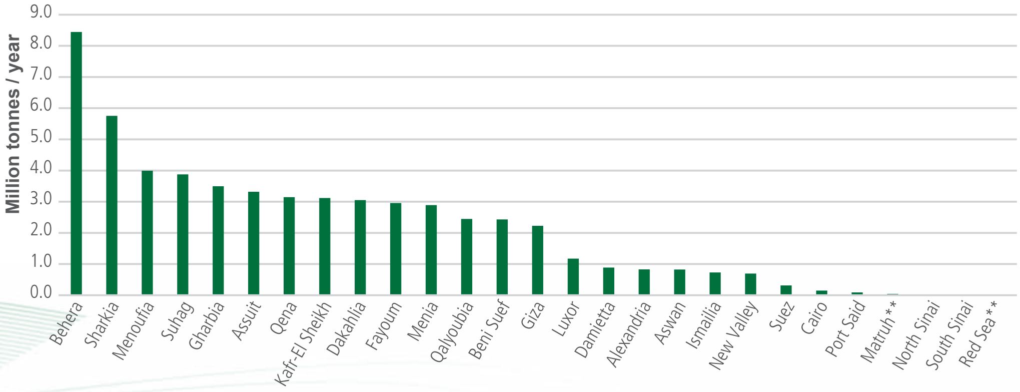
Source: Agricultural Research Center (ARC) within the Ministry of Agriculture and Land Reclamation, Egypt



Total production of cattle manure at national level was estimated at approximately 56.9 Mtonnes/year. Three governorates show the highest production levels: Behera, Sharkia and Menoufia. The shares are 15 percent, 10 percent and 7 percent respectively, accounting for about one–third of the entire national potential. These are also the top three governorates in terms of cattle numbers, so the link between manure production and quantity of livestock is quite clear. The figure below shows total production of cattle manure at governorate level.

FIGURE 26.

Total production of cattle manure – governorate level



At regional level, the Middle Delta shows the highest cattle manure production, accounting for about 50 percent (28.7 Mtonnes/year). This is followed by the Upper Egypt region, whose contribution is 23 percent (see Figure 27).

All three governorates with the highest production levels belong to the Middle Delta region and their combined contribution to this regional potential is 63 percent. Respective shares of Behera, Sharkia and Menoufia to regional manure production are 29 percent, 20 percent and 14 percent. Therefore, more than half of regional production is from the Behera, Sharkia and Menoufia governorates, while four more governorates show relatively similar shares (see Figure 27). The latter is highly indicative for several reasons. Firstly, the Middle Delta consists of eight governorates, while all the other regions are composed of fewer governorates.[10] Secondly, although the Middle Delta region has a large number of governorates, it is Egypt's smallest region, as are its governorates (generally speaking in Egyptian terms). As a result, this share implies that manure production is not widely scattered, not only in this region but also at national level. Regarding the Upper Egypt region, Figure 27 clearly shows that the three governorates make up the majority of regional manure production. Almost 80 percent of regional production is from Suhag, Assuit and Qena governorates (respectively accounting for 30 percent, 25 percent and 24 percent), which suggests that the manure produced in this region is not equally distributed and is more concentrated in these neighbouring governorates, which are situated along the Nile River.

The Middle Egypt region, consisting of five governorates, has relatively equal distribution of cattle manure, while in the Coastal region, almost 80 percent of manure produced is located in only two of the seven governorates (Alexandria 41 percent and Ismailia 36 percent). Therefore, the Coastal region shows more concentrated manure production.

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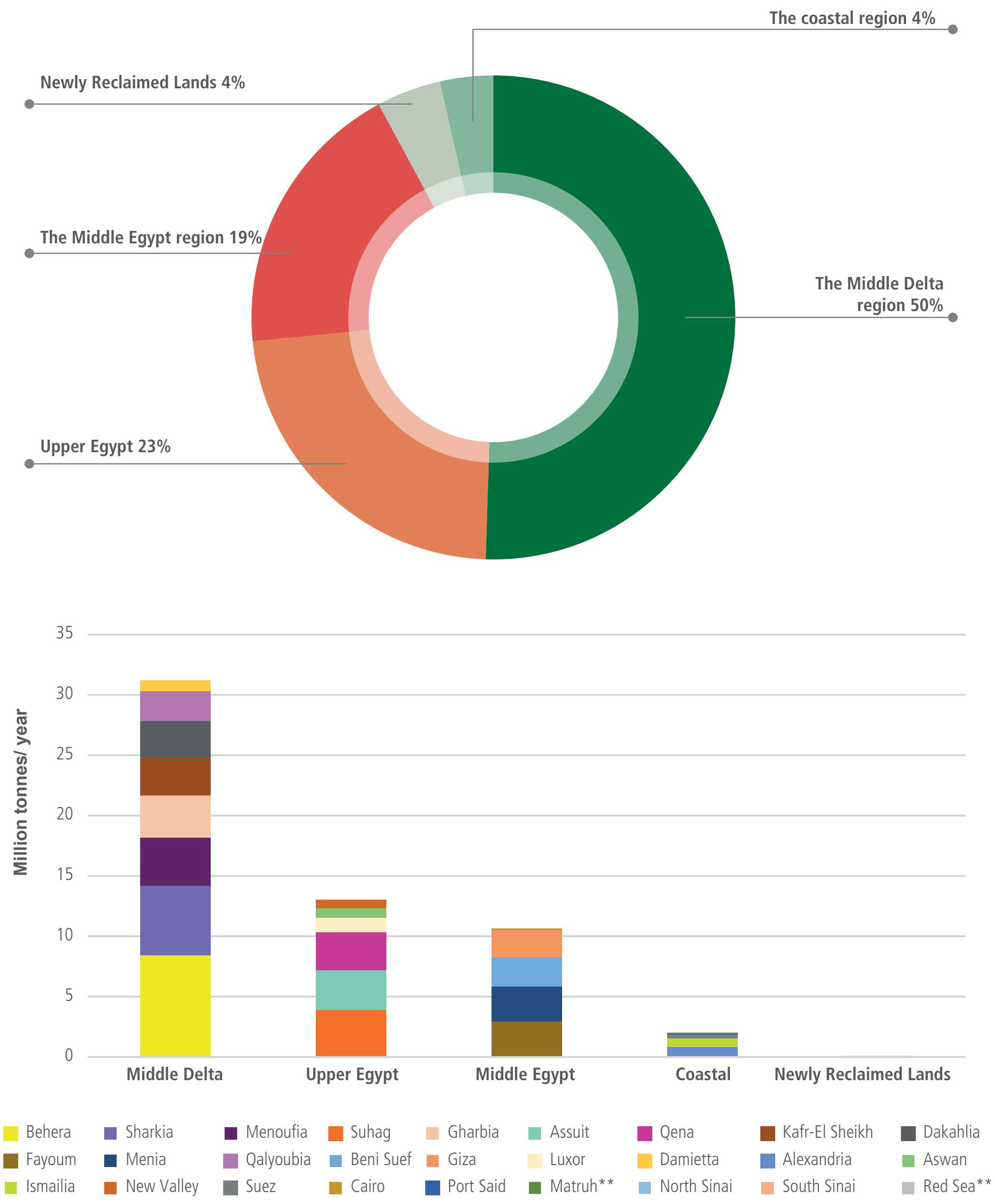
[10] It should also be borne in mind that these regions were compiled based on agro–ecological areas, rather than on administrative criteria.

FIGURE 27.

Total production of cattle manure – regional level[11]



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[11] In Figure 27, the pie chart shows that the Newly Reclaimed Lands contribute to 4 percent of overall manure production, while the column graph does not show this. The reason is that Noubaria is a zone within the Behera governorate, not a governorate in its own right. However, Noubaria, together with the Red Sea governorate, is part of the specific region. Both of these factors were reflected, which explains the different presentation between the pie chart and the graph within the same diagram.

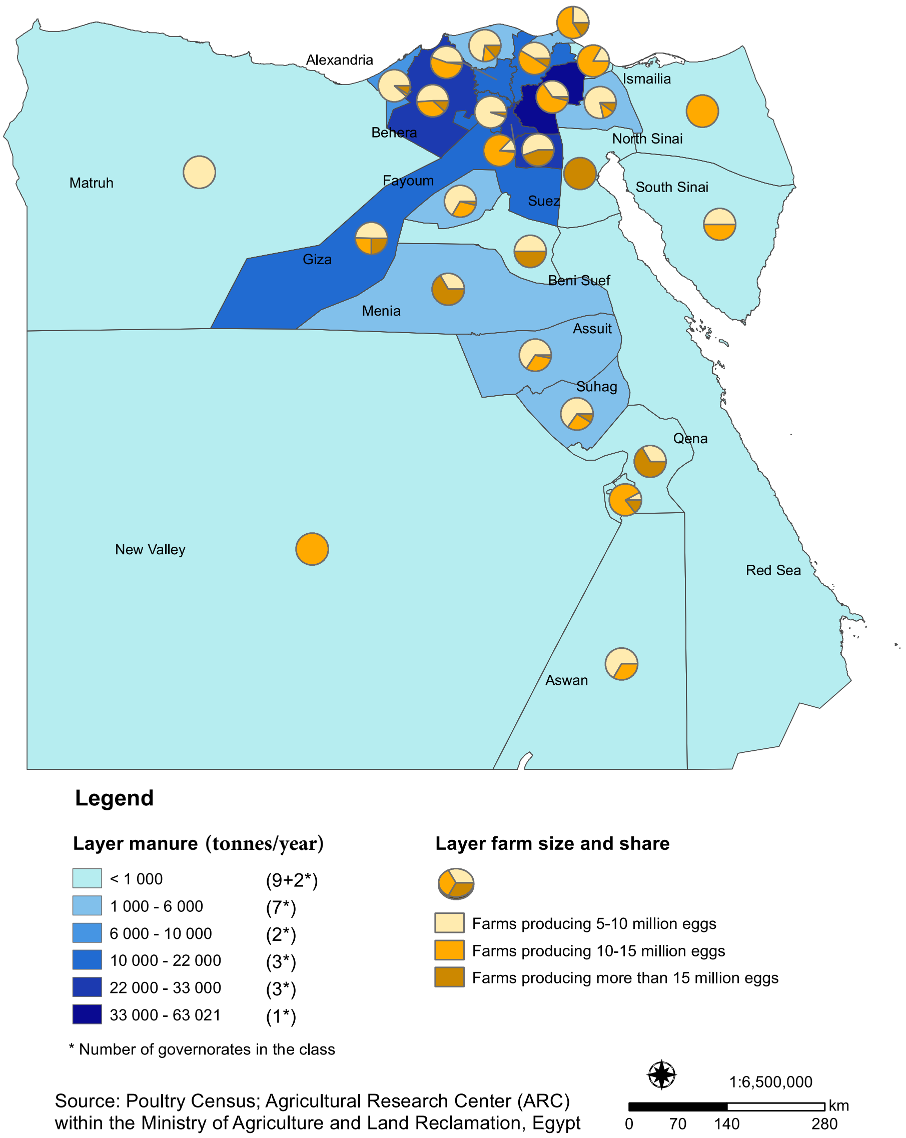
Layers and broilers

LAYERS

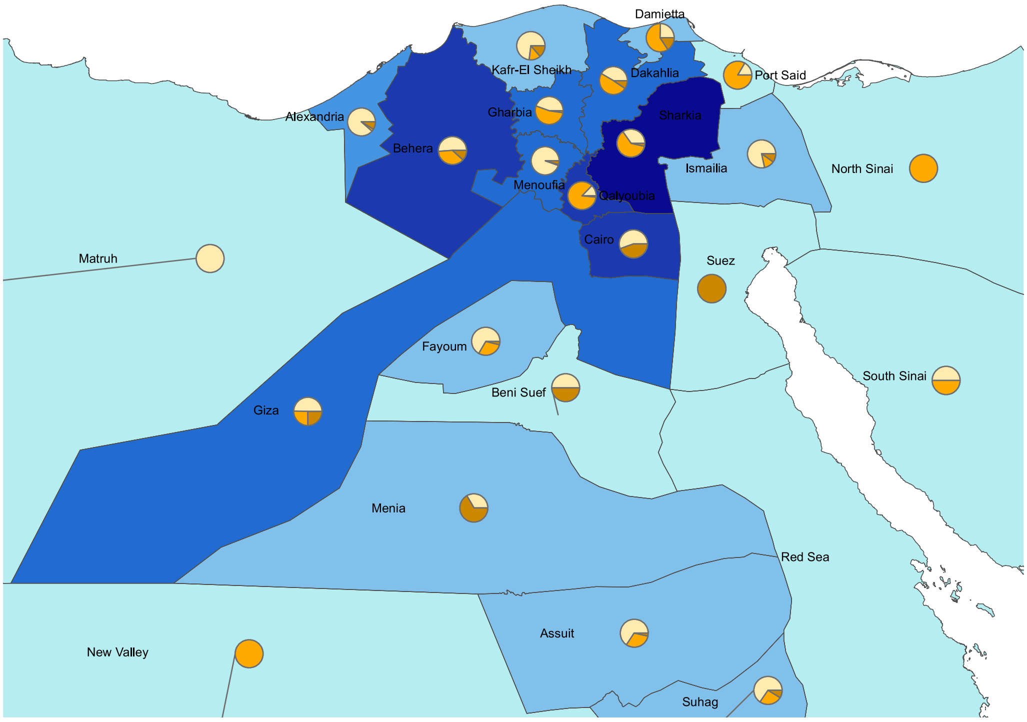
Figure 28 shows a map of the geographical distribution of layer manure production in Egypt, as well as distribution of farms across governorates. The darker blue areas represent higher manure production, while the lighter shades of blue represent a lower production rate. The map also shows the distribution of farms in the form of pie charts, varying from smallholdings (producing 5–10 million eggs), to medium–sized farms (producing 10–15 million eggs) to large–scale farms (producing more than 15 million eggs). The farm structure (size and share) is important to assessing accessibility and this will be explained later in this study.

FIGURE 28.

Map of total production of layer manure – governorate level (below spotlight on Middle Delta region)



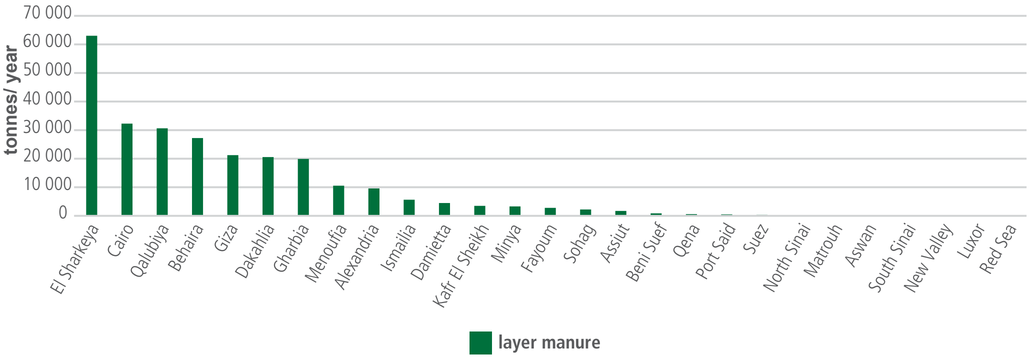
Source: Poultry Census; Agricultural Research Center (ARC) within the Ministry of Agriculture and Land Reclamation, Egypt



Total production of layer manure at national level was estimated as 261 409 tonnes/ year. The three highest producing governorates are Sharkia, Cairo and Qalubiya, accounting for 24 percent, 12 percent and 12 percent respectively. Comparing these figures to layer numbers reveals a clear link between the two – almost half of total layer manure production is located in these three governorates. Figure 35 below shows total production of layer manure at governorate level.

FIGURE 29.

Total production of layer manure – governorate level



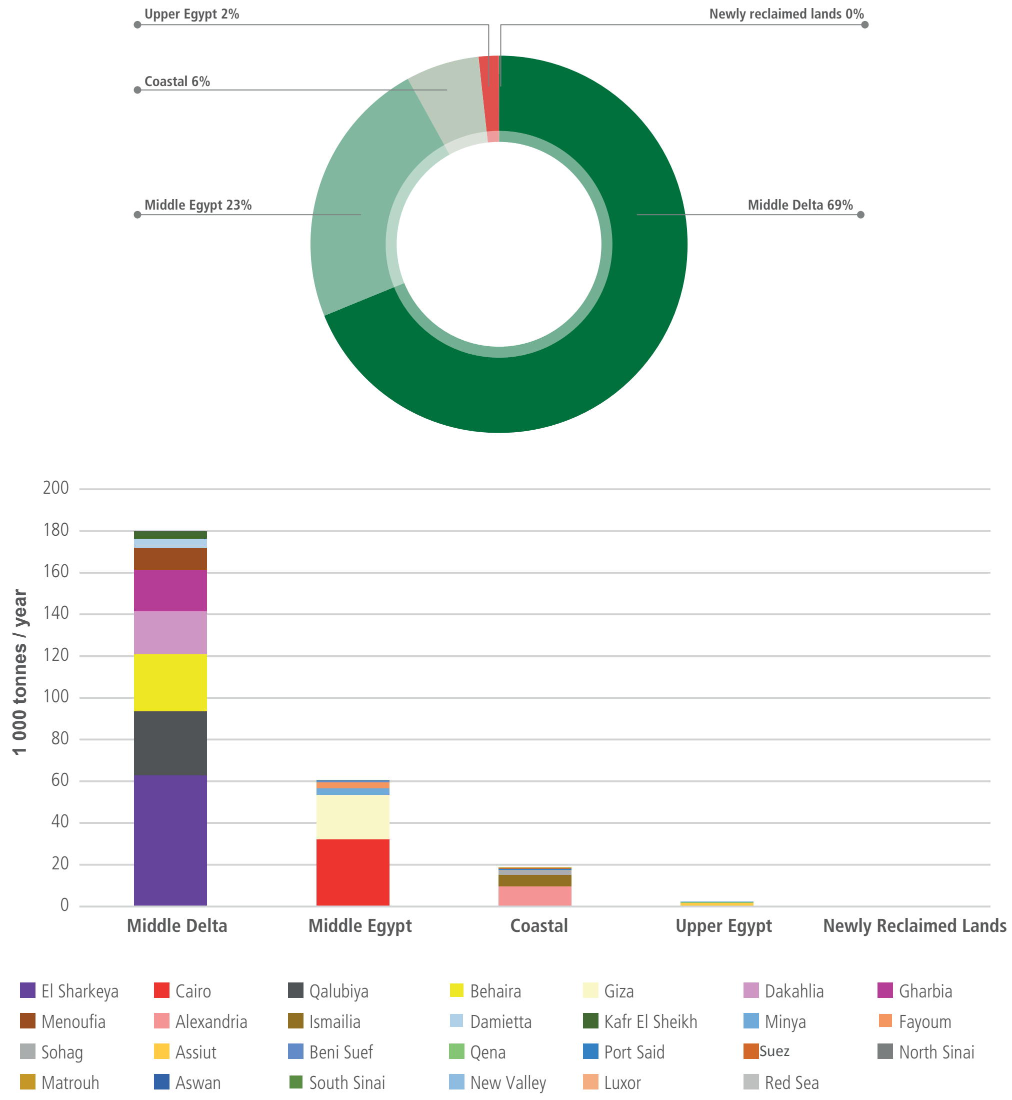
At regional level, the Middle Delta has the highest rate of layer manure production, accounting for almost 70 percent of total national production. The Middle Egypt region is in second place, with a contribution of 23 percent.

In the Middle Delta region, the highest level of production is in Sharkia, with a share of 35 percent. This is followed by Qalubyia, Behera, Dakahlia and Gharbia governorates, which account for 17 percent, 15 percent, 11 percent and 11 percent respectively. These five governorates therefore make up 90 percent of the entire Middle Delta potential. The results imply that, with the exception of Sharkia, layer manure production is equally scattered throughout this region.

For the Middle Egypt region, governorates showing the highest production levels are Cairo and Giza, with respective shares of 53 percent and 35 percent. These two governorates account for almost 90 percent of total regional potential, indicating that in this region, layer manure production is more concentrated. The same conclusion can be made for the Coastal region, where the Alexandria and Ismailia governorates account for more than 90 percent of total regional production. A similar pattern can be observed for Upper Egypt.

FIGURE 30.

Total production of layer manure – regional level

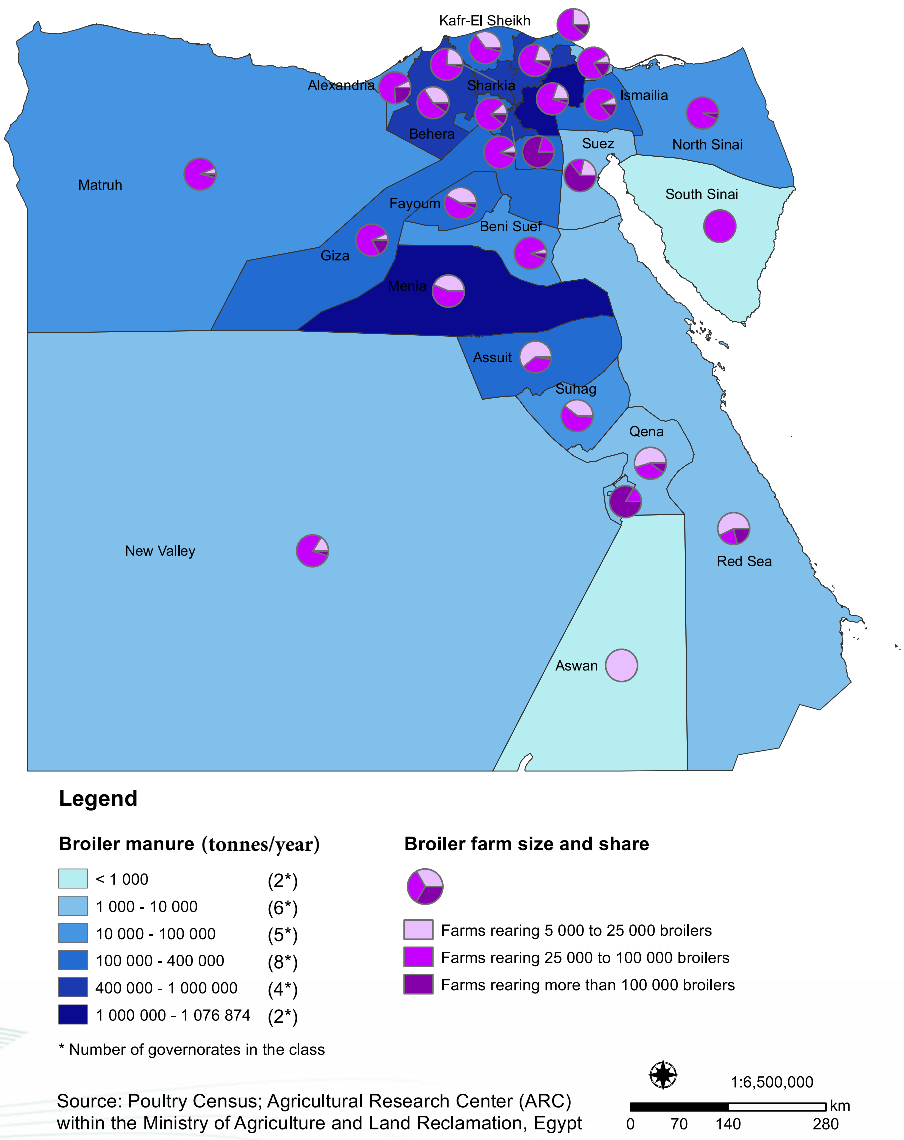


BROILERS

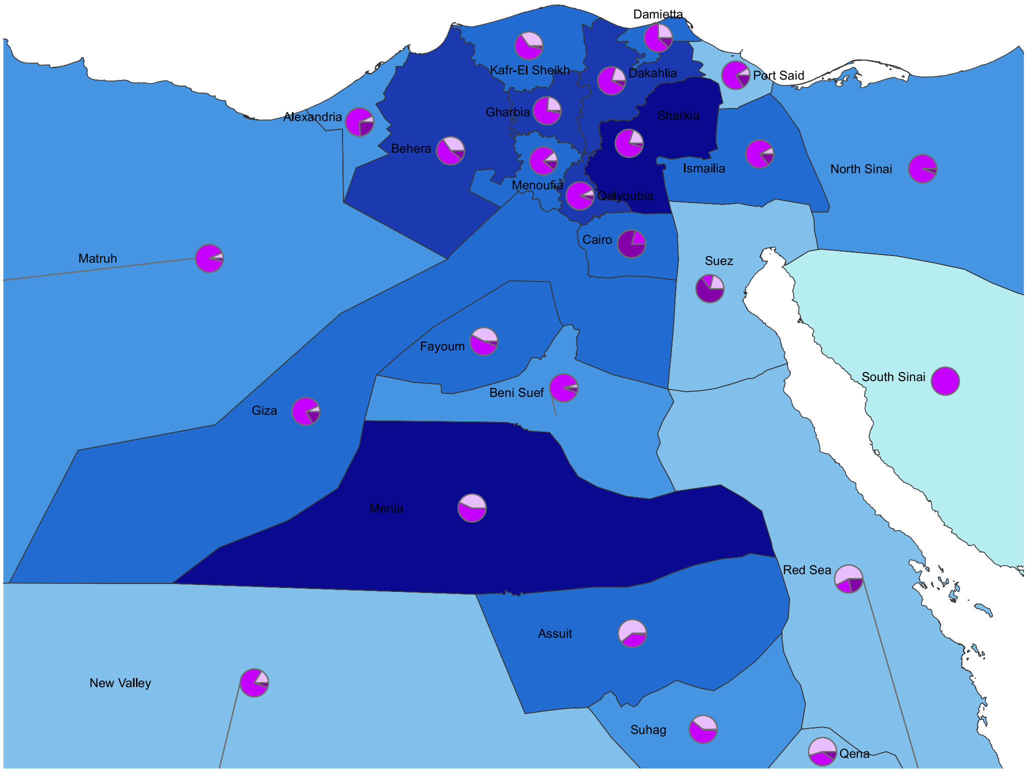
Similar to that for layers, Figure 31 shows a map of the geographical distribution of broiler manure production in Egypt, as well as the distribution of farms across governorates. The darker blue areas represent higher manure production, while the lighter shades of blue represent a lower rate of production. The distribution of farms is presented in the form of pie charts, varying from smallholdings (rearing 5 000 to 25 000 broilers) to medium–sized farms (rearing 25 000 to 100 000 broilers) to large–scale farms (rearing more than 100 000 broilers). The farm structure (size and share) is important in assessing accessibility and this will be explained later in this study.

FIGURE 31.

Map of total production of broiler manure – governorate level (below spotlight on Middle Delta region)



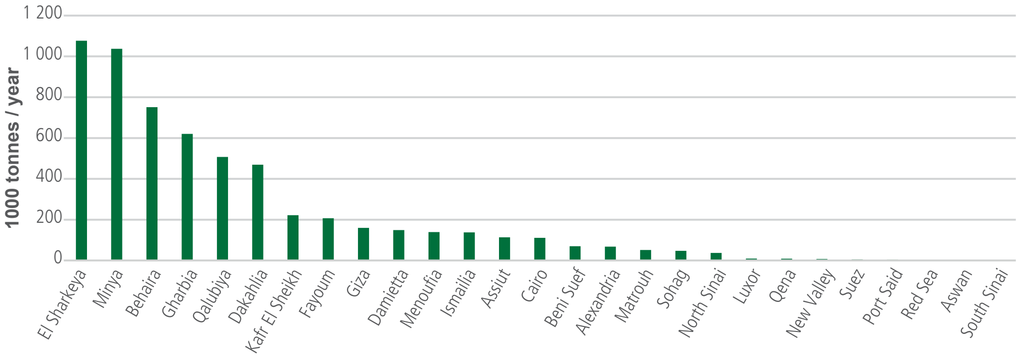
Source: Poultry Census; Agricultural Research Center (ARC) within the Ministry of Agriculture and Land Reclamation, Egypt



The estimated total production of broiler manure at national level was about 6 Mtonnes/year. The three top producing governorates areSharkia (18 percent), Minya (17 percent) and Behera (12 percent). When compared with statistics for broiler numbers, a clear link can again be observed since these were also the top three top governorates for broilers. Therefore, almost half of total production is located in these three governorates. The figure below shows the total production of broiler manure at governorate level.

FIGURE 32.

Total production of broiler manure – governorate level

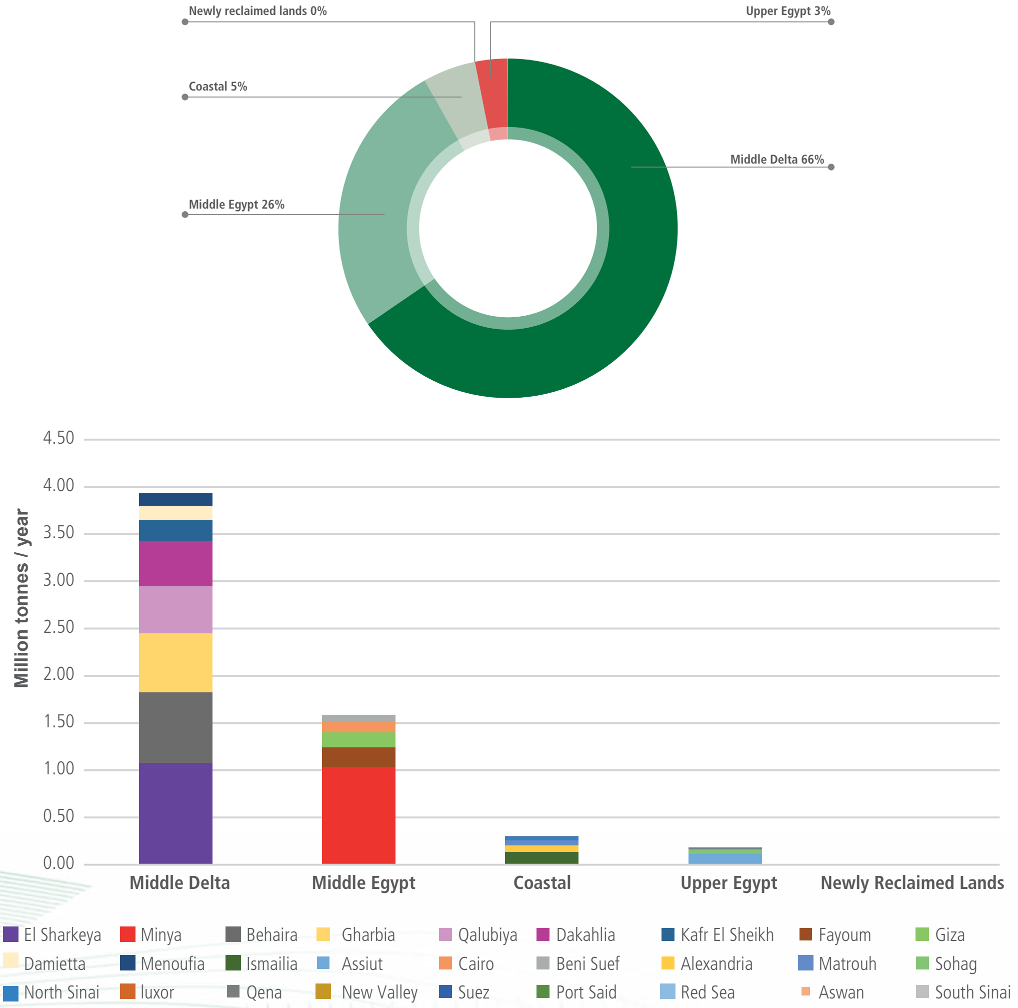


Regarding broiler manure production at regional level, the same pattern can be observed as that for layers. The Middle Delta region has the highest broiler manure production, accounting for 65 percent of total national production. The Middle Egypt region is in second place, with a contribution of 26 percent.

In the Middle Delta region, the highest production levels are estimated for Sharkia and Behera governorates, with shares of 27 percent and 19 percent respectively. As a result, these two governorates account for almost half of the entire Middle Delta potential. This implies that the potential is relatively dispersed in this region. In the Middle Delta region, Minya is the governorate with the highest production level, accounting for about 65 percent, indicating that potential is more concentrated in spatial terms. In the Coastal region, broiler manure production is mostly located in three governorates – Ismailia, Alexandria and Matrouh – with a share of 85 percent. Broiler manure potential in the Upper Egypt region is mostly concentrated in the Assuit governorate, where the share of total regional production is 61 percent.

FIGURE 33.

Total production of broiler manure – regional level



Overall, based on the number of birds and coefficients for manure production per head, total chicken manure production per year in Egypt was estimated at about 6.3 million tonnes. Of this figure, broiler manure accounts for the largest share, at almost 96 percent.

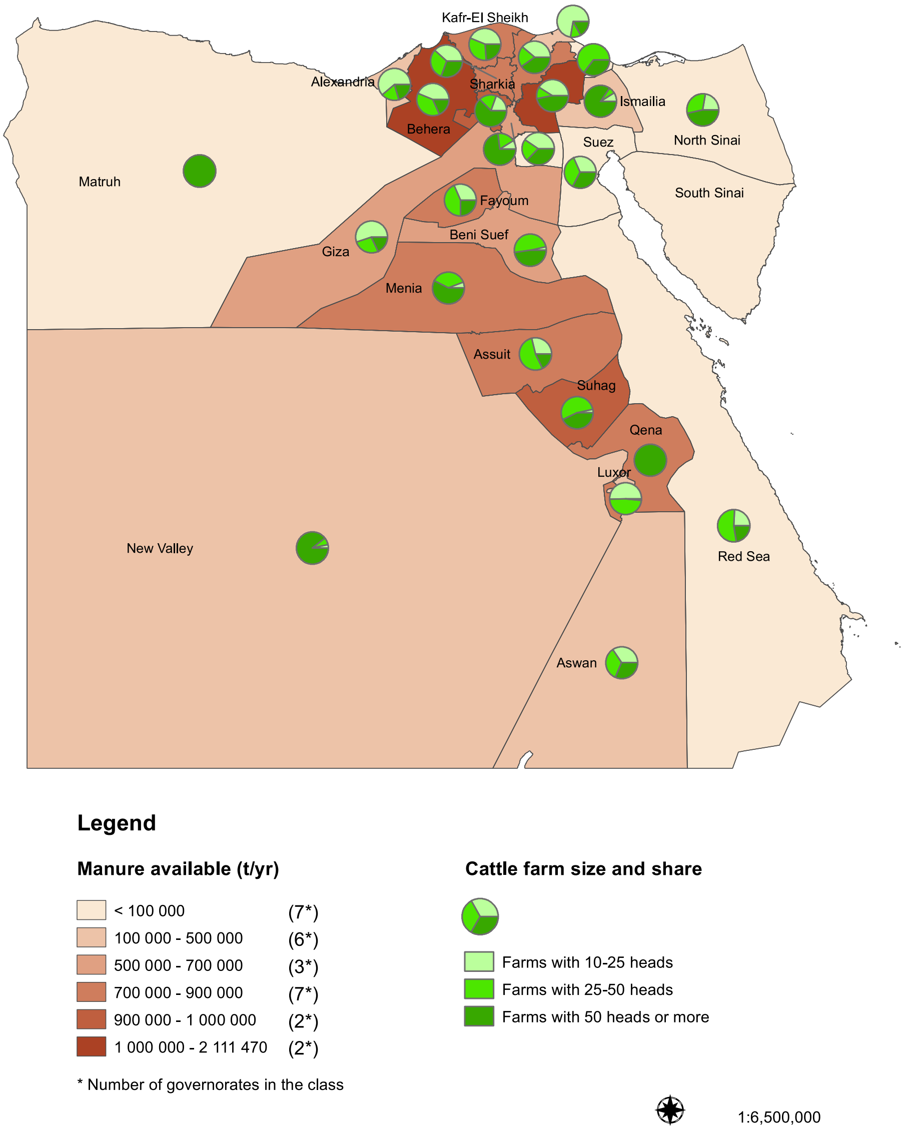
Availability of livestock residues

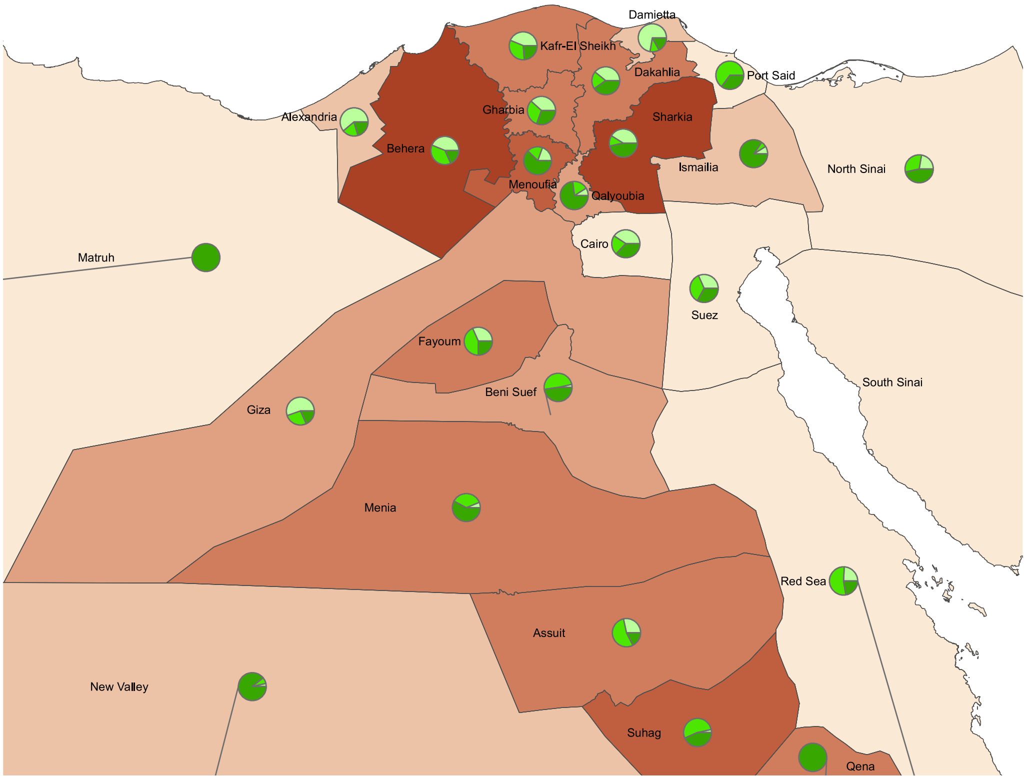
Cattle

Figure 34 shows a map of the geographical distribution of cattle manure availability in Egypt, as well as distribution of farms across governorates. The darker brown areas represent higher manure availability, while the lighter shades of brown represent lower availability. The map also shows the distribution of farms in the form of pie charts, varying from smallholdings (farms with 10–25 heads) to medium–sized farms (25–50 heads) to large–scale farms (≥ 50 heads). The farm structure (size and share) is important in assessing accessibility and this will be explained later in the study.

FIGURE 34.

Map of cattle manure availability – governorate level (below spotlight on Middle Delta region)

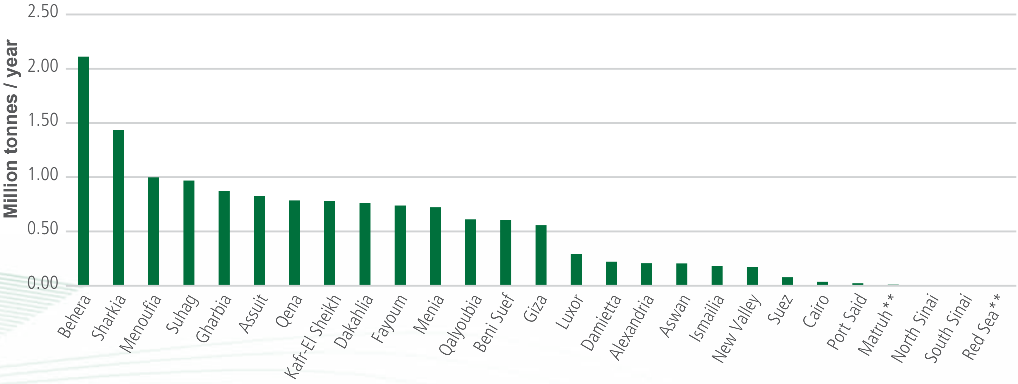




The availability of cattle manure at national level was estimated at about 14.2 Mtonnes/year, which is the equivalent of approximately 25 percent of total manure production. This figure refers to the amount remaining after all current uses have been subtracted. Two governorates show the highest availability levels: Behera and Sharkia, contributing to overall national availability with 11 percent and 10 percent respectively. The next two top contributions come from the Menoufia and Suhag governorates, with 7 percent each. Together, these four governorates therefore account for one–third of overall cattle manure availability. Figure 41 below shows total production of cattle manure at governorate level.

FIGURE 35.

Cattle manure availability – governorate level

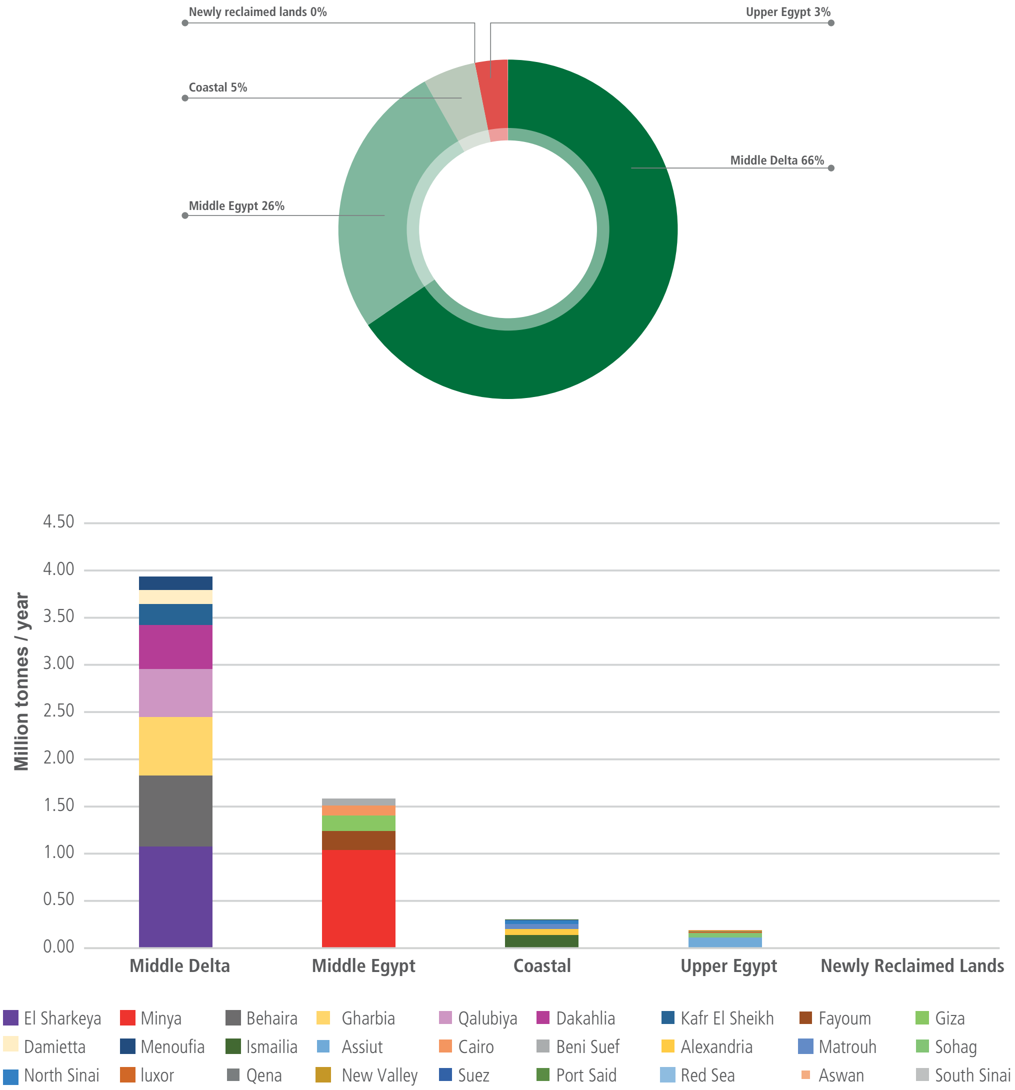


At regional level, the same pattern can be observed as in the case of manure production. The Middle Delta region has the highest cattle manure availability among all regions, accounting for 50 percent of total national production. The Upper Egypt region follows, with a contribution of 23 percent (see Figure 36).

All three governorates with the highest production levels belong to the Middle Delta region, and their combined contribution to this regional potential is 63 percent. Respective shares of Behera, Sharkia and Menoufia to regional manure production are 29 percent, 20 percent and 14 percent. Figure 36 shows that almost half of regional production is in Behera, Sharkia and Menoufia governorates, while four more governorates have a relatively similar share. This is highly indicative, due to several factors. Firstly, Middle Delta consists of eight governorates, while all other regions are composed of fewer governorates. It should also be borne in mind that these regions were compiled based on agro–ecological areas, rather than on administrative criteria. Secondly, although the Middle Delta region has a large number of governorates, it is Egypt's smallest region, as are its governorates (generally speaking in Egyptian terms). The share therefore implies that manure production is not widely scattered, not only in this region, but also nationally. Regarding the Upper Egypt region, Figure 36 clearly shows that three governorates make up the majority of regional manure production. Almost 80 percent of regional production is in Suhag, Assuit and Qena governorates (with respective shares of 30 percent, 25 percent and 24 percent). This suggests that manure produced in this region is not equally distributed and is more concentrated in these neighbouring governorates, which are situated along the Nile River.

FIGURE 36.

Cattle manure availability – regional level



A comparison between Figure 16 and Figure 35 reveals a similar pattern, highlighting the fact that cattle numbers and age are the main drivers for recorded geographical distribution of available manure. However, it should be emphasized that this result is directly dependent on the fact that the same availability factor is applied for every governorate. The next step in estimating bioenergy potential would be to collect governorate specific data through field surveys, etc.

Layers and broilers

Following the explanation in the chapter on data collection of chicken manure availability, it is conservatively assumed that no chicken manure is available for new projects.

ACCESSIBILITY OF CROP AND LIVESTOCK RESIDUES

Accessibility of residues define the share of available residues that can realistically be mobilized for bioenergy production. Even when large amounts of residues are available, collecting and mobilizing them for bioenergy production can be challenging. As a result, the concept of accessibility is important, and involves attempting to identify the proportion of available residues that can actually be used for bioenergy production. Moreover, the accessibility of residues is relevant in determining the optimal location of a bioenergy facility and the economic viability of such a project.

The accessibility of crop residues relies primarily on the type of management. Crop residues spread in the field are difficult and costly to collect. They require adequate road infrastructure to access the residues and appropriate harvesting machinery and labour availability for collection. Furthermore, in this case, the size of the cultivated parcels is important since it indicates whether cooperation with and among several farmers is needed to supply a sufficient amount of feedstock. Adequate storage facilities are also a significant factor for residues spread in the field. As a result, these residues are generally used as soil amendment and mulch, which helps to conserve moisture, improves the fertility and health of the soil and reduces weed growth. Nevertheless, in many places they are burned to prepare the field for the next cropping season, quickly and at minimal cost. This type of practice cannot be considered as an efficient use of crop residues. However, some other filed collected residues, such as hay or straw, can have relatively high accessibility. In this case too, the infrastructure elements, size of cultivated lands and storage facilities are important. Both residues spread in the field and residues collected in the field can be considered as primary crop residues, since they all originate from the field itself. Should the origin of crop residues be a processing facility, these are referred to as secondary residues. They may include rice husks, maize cob, sunflower heads, etc. Secondary residues that are produced in processing plants are usually available and accessible in relatively large quantities at the processing site itself, and may be used as an energy source for the same processing plant, involving minimal transportation and handling costs. In other cases, their accessibility also depends on the logistical infrastructure, such as road and rail network, which has a significant impact on collection and transport costs.

Accessibility of livestock residues depends largely on rearing practices, farm size, infrastructure (manure management systems), etc. One of the main parameters is whether the manure is spread in the field due to more extensive, free–range rearing practices, or if the manure is produced and available within the animal holding/farm. In the case of more extensive rearing practices, when animals spend no or little time in stables, collecting and mobilizing manure is questionable, both in practical and economic terms. The general consensus, reached across countries as a result of experience, is that using animal manure from pastures is not feasible. A suitable option is therefore collecting and mobilizing manure from animal holdings/farms. The size of an animal holding/farm, as well as the systems for manure management, are important parameters for feedstock accessibility. In general, larger farms can provide larger amounts of manure. In some cases, even one feedstock supplier could provide enough manure to run a biogas plant, which generally simplifies the implementation of such a bioenergy project. The type of manure storage and handling systems is also important to the efficient collection and use of available manure. Manure collection systems are dependent on many factors, such as bedding type, rearing system, etc. However, they require substantial financial investment. A large farm may be in a position to invest in a sophisticated manure management system, making collection more efficient and hence increasing accessibility to a high level. However, smaller farms should not be neglected, especially if they are densely located around an energy facility. In this case, cooperation with and among farmers is necessary in order to provide, not only sufficient quantities of manure, but also manure of adequate and stable quality.

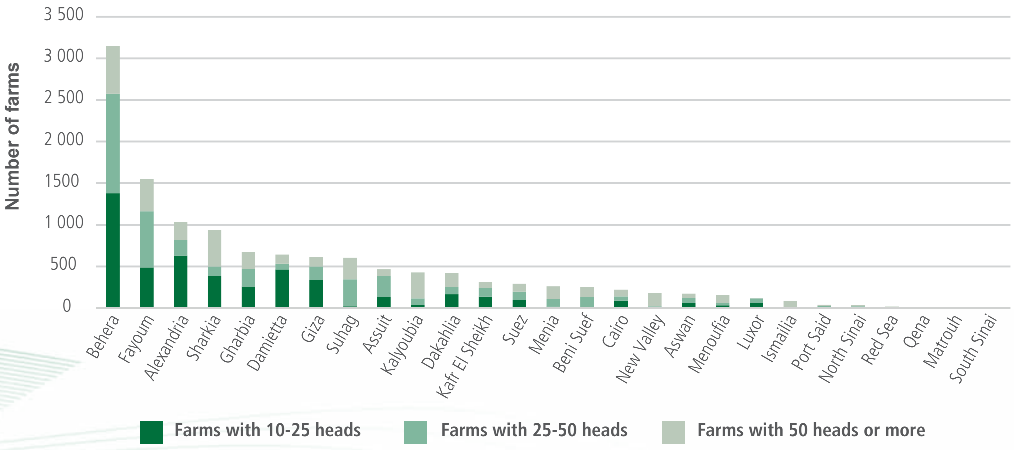
Given the importance of farm size in estimating livestock residue accessibility in this study, data on cattle farm size per governorate were collected. This is one of the initial steps in the process of estimating the level of accessibility. Based on the data collected, cattle farms in Egypt can be divided into three groups:

- Farms with 10 to 25 heads (small)
- Farms with 25 to 50 heads (medium)
- Farms with 50 heads or more (large)

Data gathered show that there are about 12 700 cattle farms (on average). At national level, approximately 38 percent of all cattle farms are small–sized (10–25 heads), 32 percent are medium–sized (25–50 heads) and the remaining 30 percent are large–sized (50 heads or more). However, this pattern differs within governorates (see Figure 37). The chart below shows that Behera is the governorate with the largest number of farms, representing almost 25 percent of all farms in Egypt. Within this governorate, most farms are classified as small, whereas in some other governorates, there are fewer farms, but more large–scale ones. However, it should be borne in mind that having even a smaller share of larger farms in Behera still has major significance in terms of accessibility, due to the fact that this governorate has a very large number of farms in general.

FIGURE 37.

Number of cattle farms – governorate level



Cattle farms with the highest share of large farms (50 heads or more) are Behera, Sharkia, Fayoum, Qalyoubia and Suhag. The first two governorates are also the top three in terms of overall number of cattle, number of cattle older than 24 months and available animal manure. In addition, Suhag is one of the top five governorates for each of these criteria. But Fayoum and Qalyoubia seem to be more significant in terms of farm number, and less in terms of manure available. A clear connection between the number of cattle and manure available was explained earlier in the study, so the sequence of the top five governorates in this regard is understandable. This is presented in Table 9.

TABLE 9.

Top five governorates based on several criteria

NUMBER OF LARGE FARMS (50 HEADS OR MORE)	TOTAL NUMBER OF CATTLE	NUMBER OF CATTLE OLDER THAN 24 MONTHS	AMOUNT OF ANIMAL MANURE AVAILABLE
Behera	Behera	Behera	Behera
Sharkia	Sharkia		Sharkia
Fayoum	Menoufia		Menoufia
Qalyoubia	Suhag	Suhag	Suhag
Suhag	Gharbia		Gharbia

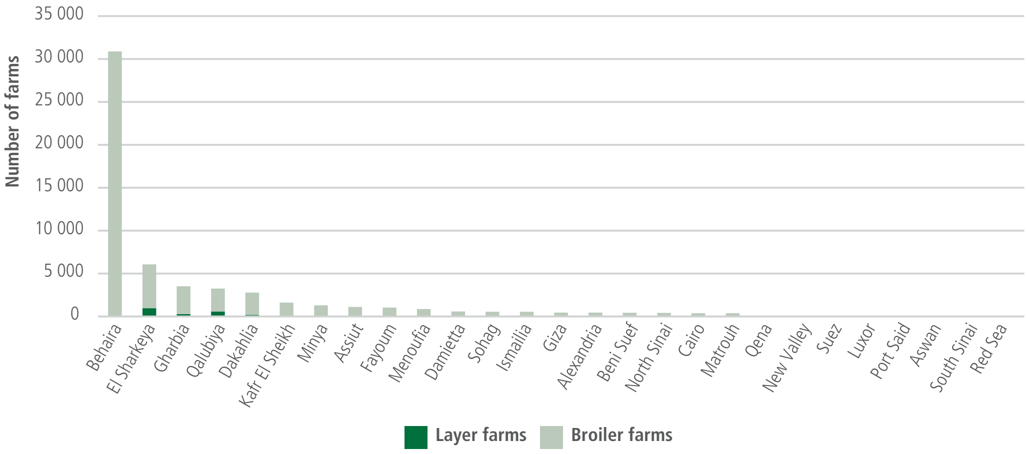
In the light of these figures, it is clear that Behera and Sharkia have the highest level of available manure, and also the greatest number of large farms, which is an indication of the accessibility of potential bioenergy feedstock. This implies that these two governorates could play an important role in any new bioenergy projects that use cattle manure. However, as previously stated, governorates with smaller amounts of available manure and with a higher number of small farms should not be neglected, as bioenergy projects may still be feasible, depending on local and project specific conditions. In order to reach any conclusion in this respect, a more detailed data analysis would be required.

With regards to chicken, the importance of different management systems has already been highlighted. Based on the poultry censuses of 2008 and 2012, there are an average of about 56 800 farms, of which 95 percent are broiler farms, i.e. farms for the production of chicken meat. The pattern also applies at governorate level, where the vast majority of farms are again broiler farms. The governorate with the highest number of farms is Behera (54 percent of all farms are located within this governorate), followed by Sharkia (11 percent) and Gharbia (6 percent). When observing layer farms only, these are most commonly found in Sharkia (37 percent of all layer farms), Qalubiya (22 percent) and Gharbia (11 percent). Broiler farms are mostly located in the Behera governorate (57 percent), followed by Sharkia (9 percent) and Gharbia (6 percent).

Figure 38 shows the number of layer and broiler farms in each governorate.

FIGURE 38.

Number of chicken farms – governorate level



The top five governorates in terms of numbers of farms are presented in Table 10. Results show that more than 80 percent of all farms (layer and broiler farms) are located within these governorates. Broiler farms are less scattered geographically, since most are located in Behera, whereas for layers, the two governorates that have the most farms are Sharkia and Qalubiya. This information indicates that governorates such as Behera and Sharkia could play an important role in any new bioenergy projects using chicken manure, if this feedstock is available. However, as in case of cattle manure, this does not mean that other governorates are less attractive. In order to reach further conclusions, more information is needed.

TABLE 10.

Top five governorates in terms of numbers of farms

TOTAL NUMBER OF FARMS		LAYER FARMS		BROILER FARMS	
Behera	54 percent	Sharkia	37 percent	Behera	57 percent
Sharkia	11 percent	Qalubiya	22 percent	Sharkia	9 percent
Gharbia	6 percent	Gharbia	11 percent	Gharbia	6 percent
Qalubiya	6 percent	Dakahlia	7 percent	Qalubiya	5 percent
Dakahlia	5 percent	Menoufia	4 percent	Dakahlia	5 percent
TOTAL	**82 percent**	**TOTAL**	**81 percent**	**TOTAL**	**82 percent**

Figures 31, 34, 37 and 40, presented in the previous chapters, show the share of cattle farms per size category and the share of chicken farms per management category for each governorate.

CONCLUSIONS REGARDING THE NATURAL RESOURCES ASSESSMENT

Based on the residue types identified, the biomass assessment analysis estimated the amount of residues produced and potentially available for bioenergy production, as well as their geographical distribution within Egypt per governorate. Crop and livestock residues were examined within the analysis.

In both cases, the assessment covered production and availability and lists the issues that would need to be addressed in terms of accessibility of residues. In general, the Middle Delta region shows larger potential availability of both crop and livestock residues. The total available quantity of residues for bioenergy production was estimated to be around 5 Mtonnes/year. **Maize stalks, rice straw, sugar cane bagasse** and **cotton stalk** were the top four most available residues in the country, each having an availability of more 500 000 tonnes/year. These four residues account for approximately 80 percent of the total availability potential.

Among the four most available residues in Egypt, maize stalk, rice straw and cotton stalk are mostly available in the Middle Delta region, while sugar cane bagasse is most available in the Upper Egypt region. Behra, Dakahlia and Quena are the governorates with the largest availability of the top four available residues in the country, with each governorate having more than 100 000 tonnes of residue available per year (see Table 16).

TABLE 11.

Top governorates producing most available residues

RESIDUE NAME	MOST AVAILABLE IN	AVAILABILITY (TONNES/ YEAR)
Maize stalk	Behera	236 117
Rice straw	Dakahlia	323 895
Sugar cane bagasse	Qena	280 079
Cotton stalk	Behera	148 055

In addition to these residues, prunings from various fruit production are promising feedstock for bioenergy production, given their physical characteristics and higher calorific values. The total availability of prunings from citrus and orange, olive, grape and palm date production was estimated to be around 777 000 tonnes. The Middle Delta region has the highest share of prunings, with 58 percent of total availability concentrated in the region. This region also has the highest availability of each pruning type, with the exception of olive prunings, 55 percent of which is concentrated in the Coastal region. Behra is the leading governorate in terms of availability of prunings, with 300 000 tonnes available per year, followed by Kafr–El Sheikh, Sharkia and North Sinai, each of which has more than 50 000 tonnes available per year.

Nevertheless, it should be stressed that that collecting and mobilizing residues that are spread in the field can be expensive and challenging, requiring considerable logistics and coordination among various actors along the bioenergy value chain. The results should therefore be considered as an initial indication of residue availability for energy production. Further examination would be required to assess the real accessible amount of these residues. Accessibility is very location specific, and would need to be determined at local level. As a result, it should be noted that the results of this analysis are an indication of where to focus these efforts further.

In the case of livestock residues, the total amount of manure available for bioenergy use was estimated to be around 14 Mtonnes/year. The availability of cattle manure was found to be highest in the Middle Delta region, with 7.8 Mtonnes/year, representing approximately half of the overall available amount in Egypt.

At governorate level, Behra and Sharkia show the largest availability of cattle manure, with 2.1 Mtonnes and 1.4 Mtonnes of available manure annually. Together, these two governorates account for 25 percent of total cattle manure available in Egypt. Additionally, of the 27 governorates, 12 show availability of between 0.5 and 1 Mtonnes of manure, while 12 others have less than 500 000 tonnes of manure available per year.

The size of cattle farms and the rearing practices followed are significant factors affecting the actual accessibility of cattle residues. Larger farms that have some form of manure management system in place can supply greater amounts of manure at lower costs compared with small farms.

TABLE 12.

Top 4 governorates with highest availability of cattle manure

GOVERNORATES	REGION	AVAILABILITY (TONNES/ YEAR)
Behera	Middle Delta	2 111 470
Sharkia	Middle Delta	1 438 257
Menoufia	Middle Delta	998 173
Suhag	Upper Egypt	969 526

For this reason, data on cattle farm sizes per governorate were collected. The analysis indicated that the governorates of Behera, Sharkia, Fayoum, Qalyoubia and Suhag had the biggest share of large farms (50 heads or more) in the country. However, given the distribution of farm sizes, the final availability estimate resulted in 6 Mtonnes/year.

The analysis of chicken manure was divided into broiler and layer outputs. This was primarily due to the differences in the physical and chemical properties of their manure. It was estimated that around 6.3 Mtonnes of chicken manure is produced every year, of which the share of broiler manure is around 96 percent. The top two governorates showing the highest production of broiler manure are Sharkia and Minya, which together contribute 35 percent to total broiler manure production. Sharkia is also the most important governorate for layer manure production, with a share of 24 percent.

As in the case of cattle manure, technical consultations were conducted with national experts to understand current management and use practices for chicken manure. These consultations indicated that only about 5 percent of chicken manure could be considered potentially available for new bioenergy projects. Given that this share is very low, and to avoid overestimating the actual availability of chicken manure, it was assumed that there is no chicken manure available for new projects.

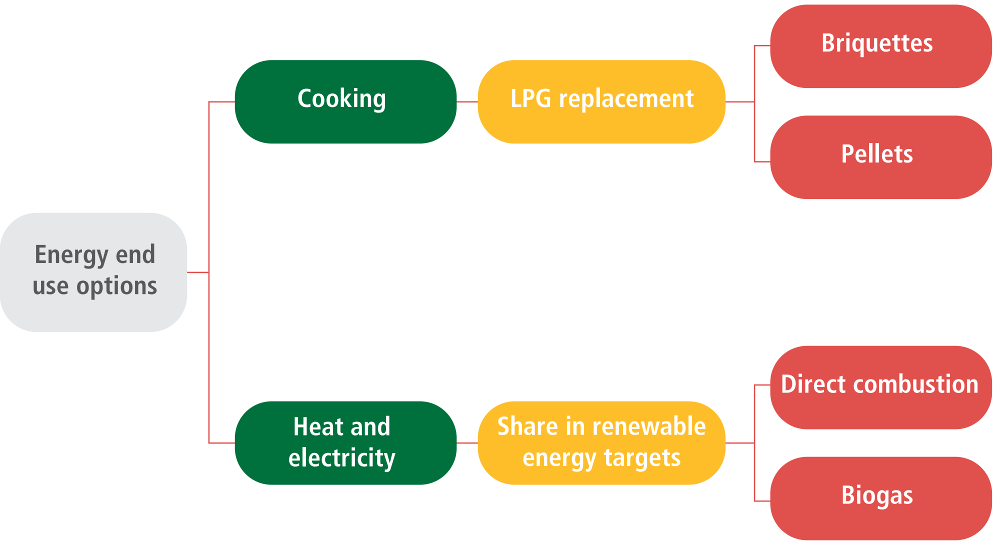
CHAPTER 2

ENERGY END USE OPTION ASSESSMENT

The energy end use options in BEFS analysis can help to understand to what extent it is possible to generate sustainable and profitable bioenergy using the natural resources available in a given country. The starting point for this assessment is defining the specific energy form of interest in Egypt. A rapid rise in per capita electricity consumption in Egypt over the past 20 years has increased interest in renewable energies. In Egypt, investment and policy support has focused on hydro, wind and photovoltaic power plant options (RCREEE, 2016). However, biomass–based electricity production also offers an opportunity to give added value to biomass residues, participating in the renewable energy matrix. The bioelectricity option is gaining ground in the country as a strategy for supplying local energy needs using biomass residues that are locally available. Conversely, as explained in previous chapters, strong demand for fossil–based LPG for cooking has generated interest in finding an affordable alternative option – one that would lead to a reduction in reliance on this fossil fuel and on energy prices for consumers, and for the government that subsidizes them. Given all these factors, the end use options considered in this BEFS analysis include briquettes and pellets for cooking, cogeneration of heat and power from direct biomass and biogas for electricity.

FIGURE 39.

Energy end use options selected for BEFS analysis in Egypt



This section assesses the various energy end use options that may be technically and economically viable in Egypt, based on the results of the natural resources assessment. A techno–economic and socio–economic analysis was conducted to evaluate the bioenergy potential, taking into account the technical viability, economic profitability, socio–economic impacts and environmental sustainability of the bioenergy technologies under consideration.

OBJECTIVE OF THE TECHNO–ECONOMIC ANALYSIS

The main objective of the energy end use option assessment for Egypt was to understand how the biomass potential identified in the natural resources assessment for different governorates might be transformed into potentially profitable and technically feasible bioenergy options. Additionally, considering the combination of feedstock, technologies and profitable production conditions, the aim was analyse to what extent Egyptian renewable energy targets for biomass could be met using sustainable bioenergy.

This main objective was fulfilled by completing the following specific objectives:

- Identify profitable production conditions for cogeneration of heat and power, briquette and pellet production from Egyptian biomass residues, considering technology options, production schemes, feedstock quality and costs;
- Define competitive production conditions for selected residues, considering the energy pathways and technologies;
- Create a ranking for the most promising feedstock, considering the amounts of biomass identified, profitable production conditions and competitive feedstock conditions; and
- Estimate the contribution of bioenergy to Egyptian renewable energy targets, given the combined energy production capacity of the different governorates.

DESCRIPTION OF TECHNOLOGIES COVERED

Cogeneration

Cogeneration systems are a thermodynamically efficient way of producing energy, and can satisfy both heat and power requirements. The surplus electricity produced can be sold to the electricity public grid. The combined production of mechanical and thermal energy using a simple energy source, such as oil, coal, natural gas or biomass, allows significant cost and energy savings to be made, as well as greater operating efficiencies compared with systems designed to produce heat and power separately. The main advantage of a cogeneration system is that less energy is consumed to produce the same amount of energy, compared with separate heat and power production systems (Quintero *et al.*, 2011; Rincón *et al.*, 2013; Rincón *et al.*, 2014a).

The current section details the techno–economic analysis of biomass–powered cogeneration plants. In this type of system, biomass is used as a main fuel source, while fossil fuels are only used to supplement energy demands not supplied using biomass, in a scheme called co–firing (Kuprianov *et al.*, 2006). Steam is a key element in a cogeneration system, which is primarily used as a means to transport energy. Steam has several advantages over other energy carriers, such as low toxicity, ease of transportability, high efficiency, high heat capacity and relatively low costs. Steam holds a significant amount of energy on a unit mass basis, which can be extracted as mechanical work through a turbine or as heat for process use. Since most of the heat content of steam is stored as latent heat, large quantities of heat can be transferred efficiently at a constant temperature, which is a useful attribute in many process–heating applications (Sanjay *et al.*, 2009; Prasad, 1995; Zheng and Furimsky, 2003).

A cogeneration system must be selected according to particular energy requirements of the plant, but taking into account all energy requirements. Some plants use systems that produce more electricity than heating, or more heating than electricity. This feature is considered in this work by including three cogeneration technologies:

I. Simple technology (intended for electricity production only); and
II. Semi–advanced technology (intended for cogeneration producing more electricity than heat).

The most commonly used biomass–fired cogeneration systems are based on the direct combustion of biomass, such as biomass steam turbines (Rincón *et al.*, 2014a). In its simplest configuration, the biomass is first dried and then burned on a grate, furnace or boiler, fixed, moving, or fluidized. In the combustion chamber, biomass exothermically reacts with excess air, leading to high reaction rates and high released heat. From an energy generation point of view, this reaction allows for the conversion of the chemical energy stored in biomass into usable energy, which is used to generate high–pressure steam. This steam passes through a turbine connected to a generator, producing electricity and low–pressure steam, using a technology called back–pressure steam turbine (O'Brien and Bansal, 2000). Turbo–generators are also commonly used in this configuration. If the main interest of the system is to produce electricity, a condensing steam turbine can be used. This equipment can condense steam below atmospheric pressure, so as to extract the maximum amount of energy from it. In formal terms, this is not a cogeneration system, because it only generates electricity, but for the sake of analysis it has been included in this work as a baseline. In this sense, simple technology used in this work is featured by condensing steam turbines, while semi–advanced technology used is featured by back–pressure steam turbines.

Industrial biogas

Biogas is a clean, efficient and renewable fuel produced during anaerobic digestion (AD) of wastewater, organic wastes and biomass. Biological conversion of this organic material is carried out in an oxygen–free environment that generates only biogas and biofertilizers as useful by–products. Biogas can be used in simple gas stoves for cooking and in lamps used for lighting in rural areas. It can substitute the use of fuelwood, charcoal or kerosene. Besides, it is a renewable energy source and CO_2 neutral, mainly composed of methane and carbon dioxide. At large scale, biogas can be used to generate heat and/or electricity by burning it as feedstock, to produce methanol and chemical feedstock to replace carbon and coal, among other applications.

Biogas industrial assessment comprises a number of technologies for large–scale production and its selection is highly dependent on feedstock's properties, particularly the total solids (percent). The total solids content (TS) is a measure of the suspended and dissolved solids in water. This is also a measure of the substrate availability in a stream to be converted into biogas. Consequently, a feedstock with high total solids content will require a smaller digester size than a feedstock with low total solids. Moreover, if a feedstock has solid content that is too high, digestion operation will be difficult and total solids will need to be reduced. These feedstock will then need to be mixed with water or low–solid waste, e.g. wastewater treatment sludge, to dilute the solids content to the operating range (Yang *et al.*, 2015). Anaerobic digestion operation is broadly classified in two different categories, according to the TS content: i) low solid content (LS), also called liquid anaerobic digestion, containing between 15 to 20 percent TS and ii) high solid (HS) or solid–state anaerobic digestion, with a range of between 22 to 40 percent of TS (Kangle *et al.*, 2012; Monnet, 2003; Arsova, 2010).

TABLE 13.

Type of reactor depending on the TS content

SUBSTRATE	REACTOR OPTIONS
Low total solids content (<15 percent), e.g. soluble industrial wastewater, municipal sewage, sewage sludge, aquatic/marine plants, particulate industrial wastes, animal manures	Anaerobic filter, up flow anaerobic sludge blanket reactor (UASB), fluidized bed reactor, continuous stirred tank reactor (CSTR)
High total solids content (>15 percent), e.g. municipal solid waste, agricultural residues, energy crops	Continuous stirred tank reactor (CSTR), batch reactor

Source: Adapted from (Lai et al., 2009)

In this work in particular, four technology options are considered to convert the range of feedstock identified in the natural resources assessment, which included crop residues, food processing industries residues and livestock residues. The four specific technology options used for biogas production are described below:

The Up Flow Anaerobic Sludge Blanket (UASB) is the most widely used technology for wastewater treatment worldwide (Strezov and Evans, 2015; Chan *et al.*, 2009; Abbasi *et al.*, 2012). In an UASB, the packing material is replaced by a gas collection device. These biodigesters operate in up flow mode, feeding the influent from the bottom, going through a dense sludge bed with high microbial activity and a gas–liquid–solid separation device (Strezov and Evans, 2015; Chan *et al.*, 2009). This separator device makes it possible to separate the liquid effluent, which flows out from the reactor, from the solid sludge, which remains in the digester, while the biogas is collected (Strezov and Evans, 2015). The process is based on the natural immobilization of the anaerobic bacteria, forming 1–4 nm of diameter dense granules (Chan *et al.*, 2009; Wang *et al.*, 2005).

The Continuously Stirred Tank Reactor (CSTR) is the most common and easy to use biodigester for treating feedstock with high solid concentration and chemical oxygen demand (COD) values higher than 30 000 mg/l (Chan *et al.*, 2009; Wang *et al.*, 2005). Usually, the CSTR volumes range between 500 and 700 m3m3, with an organic loading rate (OLR) ranging from 1–4 kg organic dry matter per m3 per day (Wang *et al.*, 2005). The CSTR digester is mostly used to stabilize the sludge by converting the biodegradable fractions into biogas (Massoud *et al.*, 2007). It is generally operated at high temperatures, to increase the process rates. CSTR digestion units are designed in large volumes that make perfect mixing difficult. Mixing is done mechanically or by recycling either flow or the produced biogas. Therefore, the mixing efficiency is an important factor in modelling the solids transport in the reactor and evaluation of the Solids Retention Time (SRT). Materials with very high COD loading rates (30 kg per m^3 per day) can be digested using this technology, reaching an adequate treatment at lower (Hydraulic Retention Times) HRTs (even 4 hours) (Wang *et al.*, 2005). Generally, a removal efficiency of 85–95 percent of the COD of the inlet material, and a methane content of 80–95 percent in the biogas produced, have been reported for this type of digestion (Chan *et al.*, 2009; Wang *et al.*, 2005).

Plug Flow Reactors (PFR) have a constant volume, but produce biogas at a variable pressure. The size of such digesters varies from 2.4 to 7.5 m3. PFR digesters consist of a narrow and long tank with an average length to width ratio of 5:1. The inlet and outlet of the digester are located at opposite ends and kept above ground, while the remaining parts of the digester are buried in the ground in an inclined position. As the fresh substrate is added from the inlet, the digestate flows towards the outlet at the other end of the tank. The inclined position makes it possible to separate acidogenesis and methanogenesis longitudinally, thus producing a two–phase system (Rajendran *et al.*, 2012). Although the optimal digestion in PFRs is reached at thermophilic conditions, they can be also operated at mesophilic temperatures (Strezov and Evans, 2015). Under thermophilic conditions, the HRT is usually of 15 to 20 days. In order to avoid temperature fluctuations during the night, and to maintain the process temperature, a gable or shed roof is placed on top of the digester, which acts as insulation both during day and night (Rajendran *et al.*, 2012). The optimal solids concentration of the feed is in the range of 11 to 14 percent (Abbasi *et al.*, 2012).

In the case of batch reactors, the biomass is loaded once and discharged until the end of the process. Due to their simplicity and portability, batch reactors are a good option for treating bio–waste in countries where landfilling is the most common waste management method used (Abu–Reesh, 2014). Batch reactors function in a similar way to a landfill, but at higher temperatures, and with continuous leachate recirculation the biogas yield is between 50 and 100 percent higher than in landfills (Mogal, 2013). Another advantage of batch fermentation is the possibility of recovering recyclable and other materials after the anaerobic fermentation is completed (Mogal, 2013). Since the batch digestion is simple and requires less equipment and lower levels of design work, it is typically a cheaper form of digestion (Baskar *et al.*, 2012). However, extra safety precautions must be taken to avoid explosions when unloading the reactor after digestion is complete.

Pelletizing and briquetting

Briquetting and pelleting are technologies aimed at increasing the energy density of low bulk density biomass (e.g. densification from 150–200 kg/m^3 to 900 to 1300 kg/m^3). This operation is technically called *compacting* or *densification*, and helps to convert waste materials into easy–to–handle fuels (FAO, 2014). In principle, briquettes and pellets can be generated from a number of sources, including food processing residues, crop residues, woody residues, charcoal, peat, paper and plastics (Kozicki, 2015).

Briquettes and pellets are used as fuel for heating and cooking applications, or as feedstock in other advanced energy generation technologies. Pretreatment is one of the key steps in briquette and pellet production, which is required to have an optimal particle size of 6–8 mm with 10 to 20 percent powdery component (< 4 mesh), and a moisture content of about 10 percent (Grover and Mishra, 1996). However, due to the diverse range of biomass that can be used for briquetting and pelletizing, and the particular properties associated with each type (e.g. heating value, size, moisture content and chemical composition), pretreatment is typically required to ensure that the biomass conditions are suitable for production. In this context, pretreatment processes may involve drying to remove excess moisture, size reduction (cutting, grinding) and preheating biomass (not higher than 300°C) to help loosen fibres and soften its structure, which reduces the wear of the screw press (Grover and Mishra, 1996; Bhattacharya and Kumar, 2005).

While briquettes and pellets are similar in many ways, their main differences lie in their size and production technologies. Briquettes are usually cylindrical blocks, with a diameter of 50 to 120 mm. Pellets are smaller cylindrical blocks, with a diameter of 6–12 mm. Production technologies are also different. Briquetting technologies are based on pressure compressing, while pelletizing technologies use agglomeration. This difference means that feedstock not suited to compression, due to their structural and physical properties, would be better using a pelletizing rather than a briquetting process.

Technologies for briquette and pellet production can be broadly classified in two main categories: hot press and cold press.

Hot press options use high–pressure compression of biomass at more than 1 500 bar, increasing the temperature of biomass and consequently melting the lignin contained, while biomass passes through a hole at a controlled rate. Once biomass leaves the holes, pressure is reduced and lignin cools and solidifies, binding biomass into a uniform and solid product. As a result, there is no need to use an external chemical binder, avoiding this cost (Hu *et al.*, 2014). However, it should be noted that external energy is required to perform this process at high pressure. The main hot press briquette machines are piston presses (smaller briquettes) and screw presses (larger briquettes). Conversely, agglomeration mills or strand granulators are used produce small cylindrical pellets, compressing biomass between rollers. Hot press options are mostly preferred for large–scale operations where external energy can be easily acquired (Fulford and Wheldon, 2015; Bialleck and Rein, 2011).

Cold press options operate at lower pressures, requiring low or no external electricity, but using large amounts of binder. These options are used for materials with low amounts of lignin (paper, charcoal, coal, etc.) (Fulford and Wheldon, 2015; Kaliyan and Morey,

2010) or simply when investment in hot press technologies is not feasible. In cold press technologies, particle reduced materials are mixed with a binder (starch, flour, clay, water, etc.), and a press is used to extrude the paste into a mould. It is possible to shape the briquettes manually. Once wet briquettes are produced, these must be dried allowing the binder to set and acquire the final form of the product. Cold press technologies can also be operated using electricity, though the most common practice is to operate them manually, making them the preferred option for small–scale producers (Ngusale *et al.*, 2014).

METHODOLOGY OF ANALYSIS

The analysis in the energy end use options sections generates economic, operating and financial results. The economic set of results includes profitability, e.g. production costs and investment requirements. The production costs are compared to market price and/or costs of technologies commonly used in the country for the specific energy option. Operating results include a comparison of the biomass requirement for the different plant scales versus the biomass available, as calculated in the biomass availability part of the BEFS approach, as well as the number of plants that can potentially be supplied based on the amount of biomass available, and potential households supplied. Financial results illustrate the financial viability of the energy end use option, based on the net present value.

The assessments for each of the energy pathways were developed through a conceptual design approach based on ‘knowledge’, e.g. mass and energy balances, physical properties of substances and other physiochemical parameters (Smith, 2005; Edgar *et al.*, 2001, Douglas, 1988). Techno–economic coefficients were defined and used to carry out the mass and energy balance calculations, equipment size estimation and energy requirements for the equipment in the case of each energy pathway. These coefficients were obtained through technology specific literature review (Rincón *et al.*, 2014b; Rincón *et al.*, 2014; Posada *et al.*, 2012; May, Grover and Mishra, 1996; Tumuluru *et al.*, 2010; Bhattacharya and Kumar, 2005). Representative plant sizes and technologies were selected for the analysis, based on the literature review.

A number of assumptions were considered in order to complete the assessment and adapt it to the Egyptian situation. Assumptions in the briquette and pellet analysis include: Four plant sizes were analysed and compared at the same time. Plant sizes are 4 kg/h, 40 kg/h, 400 kg/h, and 4000 kg/h. The first plant size represents manual operations, while the other three represent mechanized operations. It was assumed that manual plants operate under a cold press regime (no external energy, use of chemical binder), and mechanized operations operate under a hot press regime (use of external energy, no chemical binder). Additionally, it was assumed that the owners operate manual plants, so that there are no labour or management costs. Moreover, the owner receives the whole revenue from selling the product. Conversely, mechanized plants are formal businesses that hire personnel and have management costs. In the case of cogeneration of heat and power, the two technology options described above were used as variables, while plant sizes were calculated directly based on the combination of biomass available, energy potential of feedstock and operation regime of the plants. As a result, two CHP sets of results are presented i) CHP from direct biomass combustion and ii) CHP from biogas.

In all the result sections, technology variations or plant sizes, along with feedstock availability, feedstock costs and energy potential, will be used as variables of analysis. This sums up four analysis dimensions and attempts to cover a wide spectrum. Local raw material, energy and supplies costs, as well as salaries and prices were directly collected in the country by a local consultant (New & Renewable Energy Authority (NREA), 2016), and are included in the Annex.

Ranges of analysis

Considering the large number of results obtained in the natural resources assessment section, it was unrealistic to conduct a techno–economic analysis for every single result obtained for each feedstock. Therefore, ranges were built based on direct and indirect natural resource results, which formed the basis for the techno–economic analysis for different points within defined ranges. Thus, instead of conducting multitudes of specific techno–economic (TE) analysis for each feedstock, the methodology used for techno–economic analysis allowed identification of specific conditions under which bioenergy pathways (i.e. combination of feedstock and technology) would be promising. Thereafter, only those feedstock were analysed and deemed promising for specific bioenergy pathways that fulfilled the set of specific TE conditions. The ranges were built based on three data sources: i) Direct results of natural resources assessment, ii) Indirect results of natural resources assessment, iii) Energy content of feedstock.

Governorate level results of the natural resources assessment made it possible to identify minimum and maximum values of feedstock availabilities and residue yields. Feedstock such as sorghum stalk, broad bean straw, lentil straw, potato haulms and flax straw were excluded from the TE analysis. This was because it was observed that no sufficient quantity of these residues might be available for bioenergy production. Feedstock identified for bioenergy production are summarized in Table 14.

In addition, it was possible to identify options with no available quantities for bioenergy production. Thus, feedstock options such as sorghum stalk, broad bean straw, lentil straw, potato haulms and flax straw were excluded from the TE analysis.

TABLE 14.

Summarized results of the natural resources potential

CROP RESIDUE TYPE		AVAILABLE PER YEAR (tonnes/year)		AVAILABLE RESIDUE YIELD (tonnes/hectare)		TYPE	LOCATION AND COLLECTION STATUS	HARVESTING MONTHS
		min	max	min	max			
Sesame	Stalk	0	10 251	0.00	1.65	Crop residue	Field–spread	October-November
Maize	Stalk	0	236 117	0.00	1.80	Crop residue	Field–spread	October-November
Rice	Straw	0	323 895	0.00	1.78	Crop residue	Field–spread	October-November

CROP RESIDUE TYPE		AVAILABLE PER YEAR (tonnes/year)		AVAILABLE RESIDUE YIELD (tonnes/hectare)		TYPE	LOCATION AND COLLECTION STATUS	HARVESTING MONTHS
		min	max	min	max			
Sugar beet	Haulm	0	71 625	0.00	1.43	Crop residue	Field–spread	October–November
Citrus	Prunings	3	151 357	0.00	1.86	Woody residue	Field–spread	All year
Olive	Prunings	0	30 248	0.00	2.79	Woody residue	Field–spread	All year
Palm dates	Prunings	61	24 599	3.00	2.68	Woody residue	Field–spread	All year
Cotton	Stalk	0	148 055	0.00	3.24	Crop residue	Field–spread	October-November
Grapes	Prunings	0	82 537	0.00	2.32	Woody residue	Field–spread	All year
Sunflower	Stalk	0	9 471	0.00	2.80	Crop residue	Field–spread	October-November
Sugar cane	Bagasse	0	280 079	0.00	5.64	Crop residue	Processing	All year

Based on these values, national minimum (non–zero) and maximum values for feedstock availability were found to be 3 tonnes/year and 323 895 tonnes/year, respectively. However, this initial availability was re–examined, taking into account technical restrictions, such as logistical issues (e.g. transport, collection and storage), realistic plant capacities and desired operation scale. A feedstock availability of 1 tonnes/year is a small quantity to supply bioenergy processing plants at scales that would be interesting for this analysis, and would probably be economically unattractive. Consequently, a minimum value in the range was reset to a larger number, depending on the technology option used. For example, in the case of CHP the minimum feedstock quantity to operate a profitable plant should be 1 000 tonnes/year, while in order to include small–scale briquette or pellet production, the minimum quantity should be 10 tonnes/year. However, limitations in accessibility, collection and transport would make mobilization of all quantities of residue available to one single bioenergy plant challenging. Therefore, the maximum quantity was reduced to a more feasible value: 100 000 tonnes/year. The resulting ranges were used in TE analysis.

The natural resources assessment also includes indirect qualitative results, such as feedstock location, labour demand and accessibility of residues. Together with residue yields, these results fed into an additional level of analysis, where collection costs were calculated.

For bioenergy production from biomass residues, it is assumed that initial feedstock costs are zero. This is primarily based on the fact that through bioenergy production, the residues are in fact being upgraded into a higher value product (energy), which would otherwise pose an environmental problem requiring management. In any case, even if a residue producer is not receiving a direct income from residues, the bioenergy producer needs to at least take responsibility for collection and transport of residues to processing plants. In this sense, it is possible to state that feedstock cost can be calculated as:

$$\begin{aligned} \mathit{Feedstock\ cost}\ \left(\frac{US\$}{tonne}\right) &= \mathit{Collection\,cost}\ \left(\frac{US\$}{tonne}\right) + \mathit{Baling\ cost}\ \left(\frac{US\$}{tonne}\right) + \mathit{Transport\ cost}\ (US\$\ /tonne) \\ &+ \mathit{Income\,feedstock\ producer}(US\$\ /tonne) \end{aligned}$$

Equation 1

Where:

Collection costs: As stated above, regardless of whether or not the crop residues are being offered free to bioenergy producers, they still need to at least pay for collection of the feedstock. In this sense, this cost will depend on the feedstock location. Thus, feedstock located at processing plants or collected during harvesting is considered as already having been collected, resulting in a zero collection cost. Feedstock spread in the field after harvesting will have a collection cost for bioenergy producers. Therefore, collection cost accounts for the expense of labour and machinery for gathering crop residues in the field. Given the requirements of increasing accessibility and collection rates of crop residues, as discussed in the natural resources assessment, it is assumed that crop collection will be performed under semi–mechanized mode, where manual labour is combined with mechanical labour. More specifically, in the case of prunings, the methodology developed by Velasquez–Marti *et al.*, 2011 was considered. Where different, operations for harvesting prunings (pruning, biomass alignment between crop tracks, biomass concentration in piles, chipping and bundling) in Mediterranean tree cultivations are considered (Velázquez–Martí *et al.*, 2012).

Transport cost: Once residues are collected, they need to be transported to the bioenergy processing plant. Transport cost depends on the distances and unitary transport costs. First, this parameter will be affected by the current feedstock uses, which will determine the collection distance. In other words, for those feedstock with a large number of competitive uses, bioenergy producers will need to travel even further and visit more collection sites, in order to obtain the feedstock required. On the other hand, transport costs will depend on the state of the roads in the country, fuel prices, type of vehicle and the salaries of personnel tasked with driving the vehicle and loading and unloading the charges. In this analysis, transport distances are considered as an independent variable, and will be analysed separately from collection and baling costs.

Feedstock producer income: This value is assumed as zero in the initial stages of the analysis. However, the last part of each assessment will include the maximum profitable price that might be paid to feedstock producers by bioenergy plants independently, if feedstock is collected or sold at market price.

TABLE 15.

Collection cost for Egyptian crop residues

CROP RESIDUE TYPE		AVAILABLE RESIDUE YIELD (tonnes/hectare)		TYPE	LOCATION AND COLLECTION STATUS	HARVESTING MONTHS	TOTAL COLLECTIONS (US$/tonne)
		min	max				
Sesame	Stalk	0.00	1.65	Crop residue	Field–spread	October–November	$53.0
Maize	Stalk	0.00	1.80	Crop residue	Field–spread	October–November	$45.8
Rice	Straw	0.00	1.78	Crop residue	Field–spread	October–November	$40.1
Sugar beet	Haulm	0.00	1.43	Crop residue	Field–spread	October–November	$30.6
Citrus	Prunings	0.00	1.86	Woody residue	Field–spread	All year	$27.3
Olive	Prunings	0.00	2.79	Woody residue	Field–spread	All year	$24.3
Palm date	Prunings	3.00	2.68	Woody residue	Field–spread	All year	$19.7
Cotton	Stalk	0.00	3.24	Crop residue	Field–spread	October–November	$19.5
Grape	Prunings	0.00	2.32	Woody residue	Field–spread	All year	$19.3
Sunflower	Stalk	0.00	2.80	Crop residue	Field–spread	October–November	$19.0
Sugar cane	Bagasse	0.00	5.64	Crop residue	Processing	All year	$0.00

Values used for calculating feedstock collection and costs results are summarized in Table 15. The feedstock are classified according to their collection costs. Based on these, a range of collection costs (0 to 53 US$/tonne) was identified (transport excluded). However, in the light of suggestions by various authors that global biomass feedstock prices may increase (Daioglou *et al.*, 2016), the feedstock range selected for this assessment was extended (to 0 to 80 US$/tonne).

Residue availability and accessibility are the two main factors effecting bioenergy production.

Availability of residue is discussed in the natural resources section and is based on other competing uses.

Accessibility of residue is dependent on various parameters, including residue yield.

This factor is an indicator of current uses of residue. Residues with high yields have low current uses and are easier to collect, while residues with low yield have many different current uses and are hard to collect. It can therefore be expected that producers need to travel further to collect low yield residues, compared with high yield ones.

As a rule of thumb, transport distances for bioenergy projects beyond 25–50 km are uneconomical (Sultana and Kumar, 2012). However, for the sake of analysis, and in order to understand the effect of transport costs on the unit production cost, a range varying from 3 times the maximum collection distance in the worst case scenario (150 km) was selected as the upper boundary. For the minimum collection distance, a value of 0 km was selected. Consequently, the resulting range of analysis for collection distance was established as 0 km to 150 km.

As for the energy content of feedstock, each type will have its own chemical composition in terms of carbon, hydrogen, oxygen, nitrogen and sulphur. Relative quantities of these elements will determine the total potential energy contained in each particular feedstock. Additionally, parameters such as moisture, fixed carbon and volatile carbon will determine how easy it will be to release this potential. The combination of all these parameters is measured by the calorific value of a feedstock, or its equivalent property Low Heating Value (LHV). For this specific analysis, standard LHV collected from different literature sources was used (Lindley and Smith, 1988; Desideri and Fantozzi, 2013; Đurić *et al.*, 2014, ECN, 2012).

TABLE 16.

Energy potential for crop residues

CROP RESIDUE TYPE		LOW HEATING VALUE (MJ/kg)
Sesame	Stalk	15.92
Maize	Stalk	17.95
Rice	Straw	14.92
Sugar beet	Haulm	16.60
Citrus	Prunings	16.93
Olive	Prunings	17.40
Palm date	Prunings	18.60
Cotton	Stalk	17.09
Grape	Prunings	17.75
Sunflower	Stalk	17.19
Sugar cane	Bagasse	17.27

In the TE analysis, LHV is used as an indicator of the 'energy quality' of each type of feedstock (see Table 16). The bioenergy obtained from highly energetic feedstock would be more valuable than others derived from low–energy feedstock. For example, bioenergy products obtained from hazelnut shells will be more valuable than bioenergy products derived from apricot kernels, independent of the cost or availability. In the TE assessment, a range from 10 MJ/kg to 20 MJ/kg was used as the energy potential of feedstock.

In summary, the following values were used as ranges of analysis within the TE assessment, helping to cover the main features of all feedstock available (see Table 17).

TABLE 17.

Range analysis summary

END USE OPTION	MIN FEEDSTOCK YIELD (tonnes/ hectare)	MAX FEEDSTOCK YIELD (tonnes/ hectare)	MIN FEEDSTOCK AVAILABLE (tonnes/ year)	MAX FEEDSTOCK AVAILABLE (tonnes/ year)	MIN COL. COST (US$/ tonne)	MAX COL. COST (US$/ tonne)	MIN ENERGY POTENTIAL (MJ/kg)	MAX ENERGY POTENTIAL (MJ/kg)
Briquettes/ pellets	0.00	15	10	100 000	$ 0	$80	10	20
Cogeneration (CHP)	0.00	15	1 000	100 000	$ 0	$80	10	20

Reference Price

The reference prices of energy products were used as part of the analysis to calculate the profitability of the different energy end use options under different market conditions.

Taking the case of electricity, this is the most critical product affecting the economic performance of CHP plants. Three scenarios were built to analyse how electricity price variations would affect the profitability of energy plants in Egypt. Scenario 1 was the baseline. Here it was assumed that CHP plants would be selling electricity at the same price that is currently paid by consumers. This price was the weighted average price of electricity 2016/2017, calculated by the Ministry of Energy as 0.051 US$/kWh (EgyptERA, 2016). The second price (Scenario 2) is 0.1 US$/kWh, which is the feed-in tariff price. The third comparison price (Scenario 3) is 0.15 US$/kWh, which considers an additional 50 percent premium[12], in addition to the current feed–in tariff price. The results of the assessment show that CHP schemes would start to be economically viable from a selling price of 0.10 US$/kWh.

The other product of CHP plants is heat, and its consumers would be processing plants attached to CHP units. Thus, it was necessary to estimate the price that a typical processing plant might pay to generate heat (as steam) using fossil fuels. The value found was 3.09 US$/GJ as the average value for steam generation using natural gas, diesel or fuel oil in Egypt (New & Renewable Energy Authority (NREA), 2016). This is therefore the value that CHP plants will receive for the cogenerated heat. Given the low international fuel prices during 2014–2016, this value is low. Its normal range is 4–8 US$/GJ. This range was estimated based on the methodology provided by Union Gas Gasworks, 2016 and current oil prices in Egypt reported by El–Serag, 2015, New & Renewable Energy Authority (NREA), 2016. It can therefore be considered a conservative value.

Finally, reference prices for briquettes and pellets were also needed. Data collected in country reported that pellets have a market price ranging between 119 and 132 US$/tonne, while briquettes fetch 150 to 200 US$/tonne (New & Renewable Energy Authority (NREA), 2016). In the light of Egypt's energy target demands, LPG was used as a comparison fuel, with a price of 1 US$/cylinder.

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[12] The average price of electricity was calculated for the period based on data from the Egyptian Electric Utility and Consumer Protection Regulatory Agency (EgyptERA, 2016). The feed in tariff was considered to be 0.10 US$/kwh based on the information available at the time of the analysis. This is in line with the feed in tariff proposed by the Council of Ministers for Egypt in decision number 5/10/15/4 dated 28/10/2015, where it is stated that the feed in tariff will be 0.92 EGP/kWh (Council of Ministers for Egypt, 2015), as reported by NREA.

RESULTS

Cogeneration of heat and power results

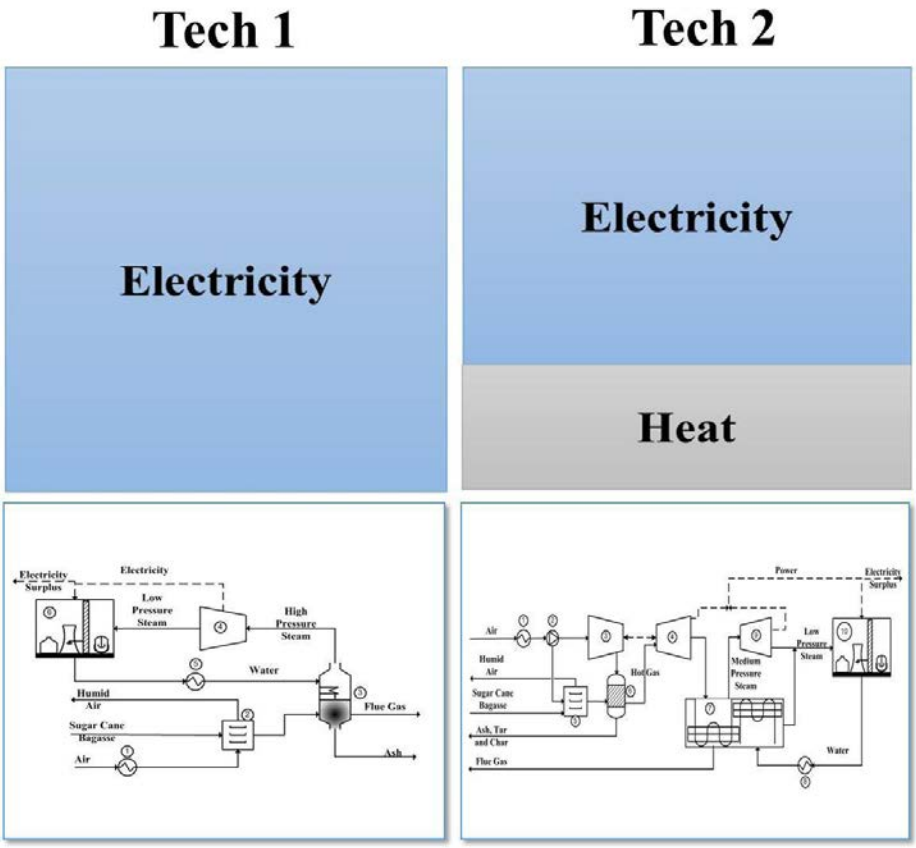
This section presents results found under the Egyptian context for CHP production using direct combustion and biogas options.

CHP options

The results obtained in the techno–economic analysis for CHP are featured, taking into consideration some of the most critical variables affecting the techno–economic viability of this kind of project: energy potential of feedstock, feedstock cost, technology and selling price of products. More specifically, on the technology side, a standard CHP technology comprising a boiler and a back–pressure turbine was used (Tech 2). For the sake of comparison, the CHP option was assessed alongside a fully dedicated bioelectricity generation technology (Tech 1) (Figure 40).

FIGURE 40.

Comparison of technologies used in this analysis - Electricity only (Tech 1) and CHP (Tech 2)



Direct combustion results

Firstly, the break–even analysis (BEA) was performed. This provides the break–even prices (BEP). It is intended to determine the conditions under which the total production cost is equal to the process revenues (El–Halwagi, 2012).

Two different BEA figures were created: i) BEA Tech 1 (see Figure 41) and ii) BEA Tech 2 (see Figure 42). Each of these figures shows prices: (US$/kWh) on the y–axis and production capacity (kWe) on the x–axis. There are a total of 9 BEPs in each chart. First, there are three different potential feedstock costs: 0 US$/tonne (low), 40 (mid) and 80 (high). Second, within each feedstock cost, there are coloured BEP lines. These coloured US$/tonne lines represent the three possible energy potentials of biomass residues: low (blue), middle (orange) and high (grey). Finally, there are three dotted lines showing the three distinct price scenarios considered in this study, allowing for a direct comparison of the BEP lines.

FIGURE 41.

Break–even analysis – Electricity only (Tech 1)

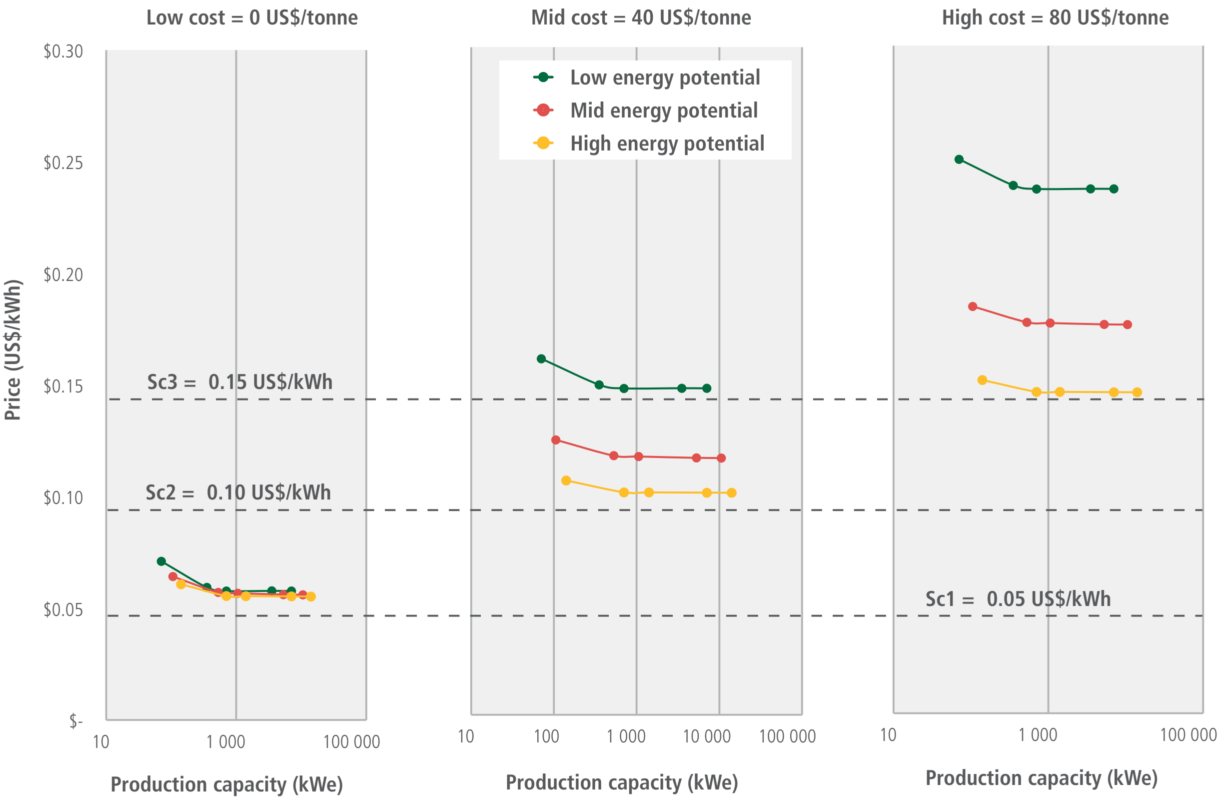
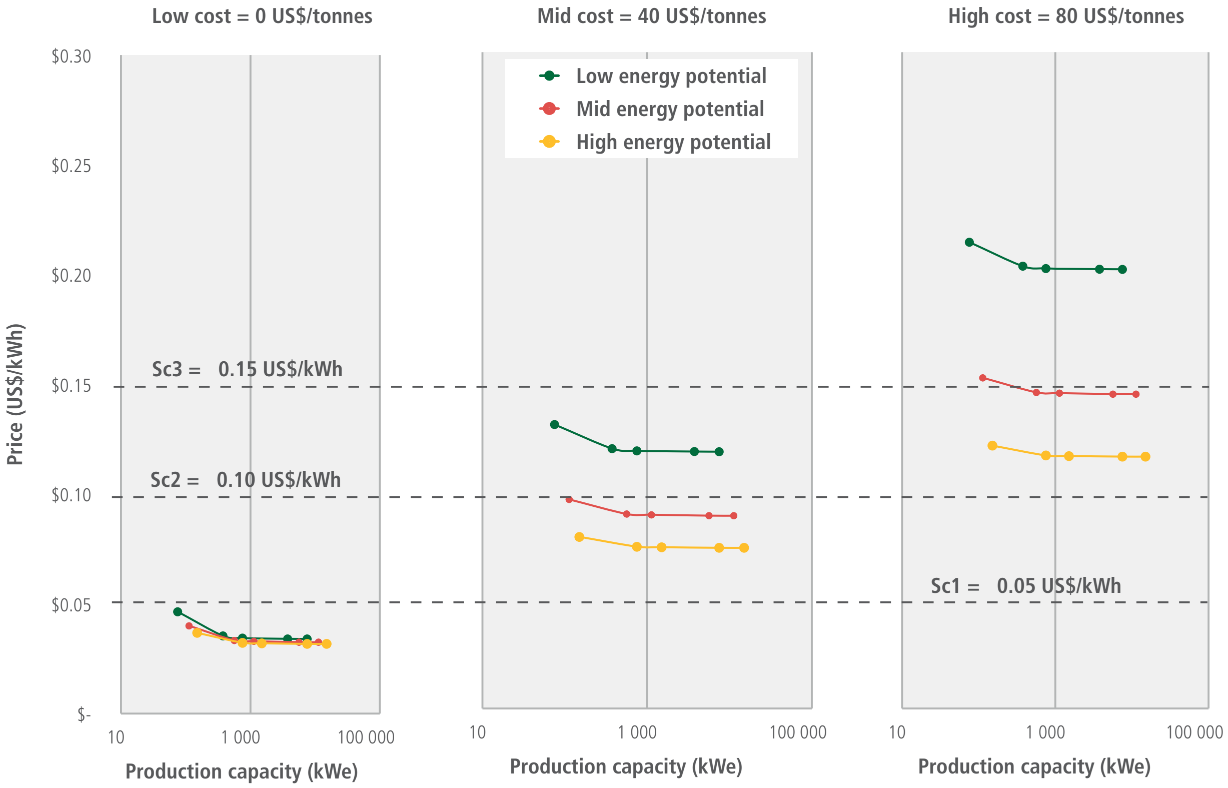


Figure 42 shows how feedstock options with higher energy potential and low costs would tend to be more competitive than those with a lower energy potential and high cost. This result can be explained by the strong influence that feedstock cost and properties have over bioenergy profitability (Schmidhuber, 2008). Thus, a feedstock producing more electricity (due to its high energy potential) will reduce the overall unitary production cost, and, as a result, lower the required BEP. Moreover, this effect is also maximized by the feedstock cost. A high–cost feedstock would have higher unitary production costs, and would emerge as less competitive than a low–cost feedstock.

When the BEA of Tech 1 (see Figure 42) is compared with Tech 2 (see Figure 42), the analysis demonstrates how technology has a remarkable impact on the amount of energy produced and on the unitary production costs. Furthermore, the comparison shows that BEPs are reduced, and more feedstock options (regarding costs and energy potential) become competitive when energy is used more efficiently, as it is in CHP systems. In addition, credits are received by the selling of heat, which is not possible in the case of Tech 1.

FIGURE 42.

Break–even analysis - CHP (Tech 2)



The results above show the importance of the biomass used in terms of energy potential and costs, but also demonstrates that the technology selected and the production capacities and revenues obtained from products and sales of products are important to determine overall profitability. This relationship is further explained by calculating an indicator of business profitability with a time–value of money, such as Net Present Value (NPV) (Equation 2). The NPV equation presents the cumulative value (revenues – expenses) adjusted to the reference time, where the term (1+i)n is the discount factor, and is called the discount rate (El–Halwagi, 2012). For this kind of bioenergy project, an acceptable discount rate ranges from 9 to 11 percent.

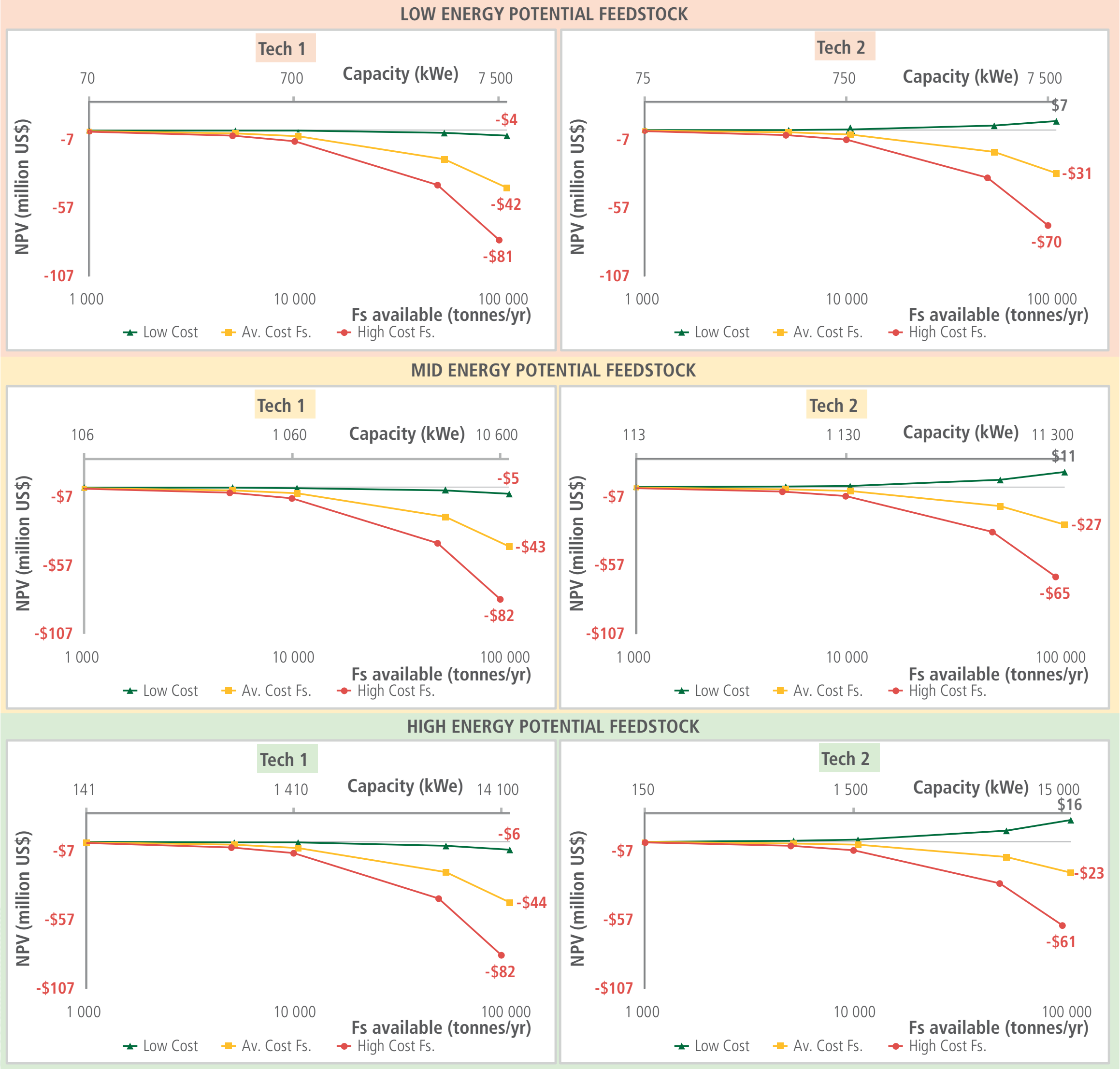
Equation 2

$$NPV = \sum_{i=0}^{n} \frac{Annual\ Cash\ Flows}{(1+i)^{n}}$$

Figure 43 shows the combination of six NPV charts obtained for Scenario 1 (i.e. electricity price = 0.05 US$/kWh). Rows in Figure 43 show NPV charts obtained under the three feedstock energy levels considered in this study. The two columns compare the NPV charts for the two technology options considered. Each chart shows NPV (million US$) on the y–axis, while the x–axis 1 displays the range of analysis for feedstock available (tonnes/year). Additionally, x–axis 2 combines the feedstock available, energy potential and technology efficiency to estimate the equivalent plant capacity (kWe) for each feedstock quantity available. Finally, each chart contains coloured lines showing the NPV variations over the feedstock available/plant capacities range. Each colour belongs to a different feedstock cost level: low (blue), average (green) and high (orange). Moreover, NPV values obtained for the maximum feedstock available/production capacity were included as indicators of the overall tendency of NPV lines.

FIGURE 43.

NPV (million US$) – Scenario 1



The above results show that in the long term, Tech 1 (i.e. electricity production only) is not competitive under Scenario 1 prices (i.e. 0.05 US$/kWh), despite changes in energy potential, feedstock costs, and/or production capacities. Conversely, Tech 2 (i.e. CHP) would be competitive under a set of stringent specifications for plant sizes and with feedstock costs as low as possible.

This finding is again a clear indicator of the role played by feedstock cost in biomass–based projects. Additionally, it illustrates that a price ceiling must be set for the feedstock, according to the technology used and the energy quality of feedstock. This price ceiling is the maximum price that a CHP producer is able to pay for the biomass and it operates as an upper limit, which if exceeded means that profitability has started to decline. Table 18 demonstrates these considerations.

TABLE 18.

Maximum acceptable feedstock prices – Scenario 1

ENERGY POTENTIAL (MJ/kg)	MAX FEEDSTOCK PRICE (US$/tonne)	
	Tech1	Tech 2
<13	Not profitable	US$10
<15	Not profitable	US$12
<17	Not profitable	US$13
<19	Not profitable	US$16

Additionally, Table 18 shows that if the bioenergy producer receives 0.05 US$/kWh for the electricity generated, then the best option when using CHP technologies would be to rely on high energy feedstock. This would mean paying up to 16 US$/tonne for very valuable feedstock (i.e. energy potential <19 MJ/kg). Having the highest price ceiling, the most valuable feedstock has the greatest flexibility in terms of changes in feedstock prices, compared with low energy feedstock. Still, specific feedstock costs are highly dependent on factors such as the country context, availability, accessibility, etc. Various authors agree that market prices for biomass residues normally range from 50 to 150 US$/tonne in different scenarios of world projections for availability and costs of agricultural and forestry residues (Chen, 2016; Daioglou *et al.*, 2016; Nakomcic–Smaragdakis *et al.*, 2016). When compared to this range, the estimated price ceiling of 16 US$/tonne is quite low. As a result, only bioenergy plants obtaining feedstock at low costs (less than 16 US$/tonne) in Scenario 1 would remain competitive, but would still be under threat from increases in feedstock prices, possibly due to other competing uses or shortages in production.

The next step of the analysis requires contextualizing these results for the particular Egyptian framework. Thus, considering the set of feedstock options identified as potentially available in the natural resources assessment (and which can be used in CHP applications, from a technical point of view), energy potential and feedstock costs identified in the methodology section are summarized in Figure 44. The feedstock costs were calculated based on the natural resources assessment results.

FIGURE 44.

Comparison chart for energy potential and estimated collection costs of feedstock selected for CHP direct combustion

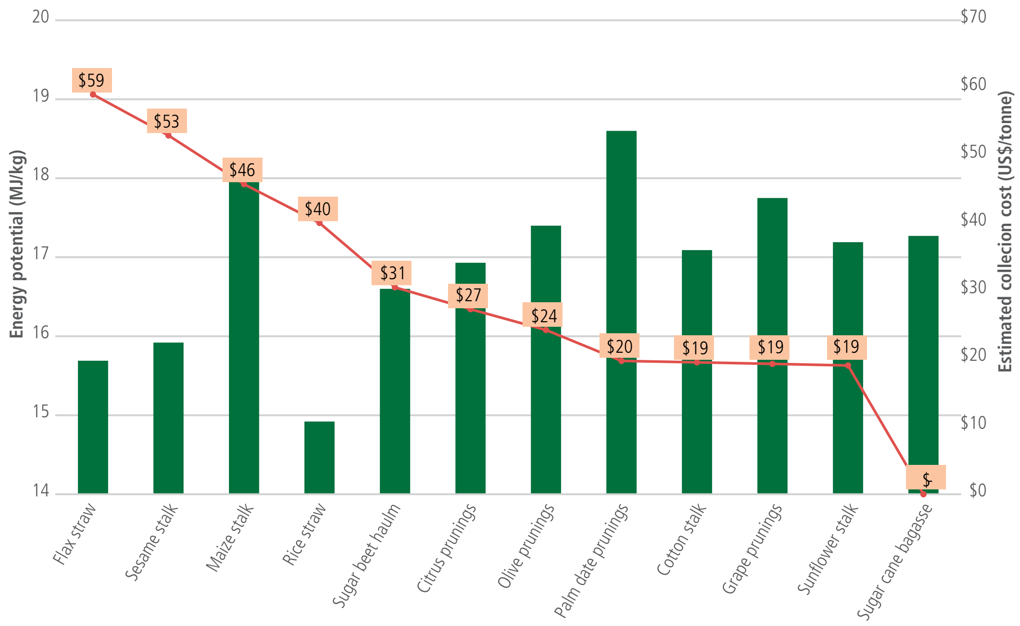


Figure 44 summarizes the two types of feedstock option considered for the CHP scenario: woody residues (all prunings) and crop residues (both spread in the field and collected). This figure shows that there is no direct relationship between energy potential and collection costs. It might happen that a very valuable feedstock from an energy point of view has low collection costs. On the other hand, feedstock with low energy potential can have high collection costs. This can be explained by the fact that collection costs and market prices are highly dependent on feedstock availability and not necessarily on the energy properties of feedstock.

Once the results that feature a set of profitable conditions for CHP production were obtained, the next step required an analysis of how Egyptian feedstock (Figure 44) might emerge as profitable or not under these conditions. At this point, it is necessary to introduce Profitability Zones Maps. This concept was created to simplify the use of profitable production criteria. In these maps, feedstock are located according to their energy potential and feedstock costs are plotted on an X–Y chart.

The maps comprise three zones marked in different colours and defined according to the maximum feedstock costs identified for each energy potential within each scenario (see Figure 45). The green zone includes feedstock with energy potential and/or feedstock cost that fulfils profitable production criteria for all technology options and plant sizes (see Figure 45, Zone A). The yellow zone encompasses feedstock that might be profitable under specific criteria: certain plant sizes or technologies (see Figure 45, Zone B). Finally, the red zone contains feedstock which do not meet profitability requirements at all see Figure 45, Zone C). These Profitability Zones Maps are also useful in identifying the maximum price that any given feedstock should cost under a set of production conditions. As an example, a CHP project using feedstock with the energy potential of 17 MJ/kg could be profitable if the price for that feedstock is less than 50 US$/tonne, using any cogeneration technology and/or plant capacity. However, if the feedstock price is increased to 75 US$/tonne, then the CHP project profitability might be at risk, and this option would only be profitable using certain technologies and plant sizes. Finally, if the price of this same feedstock were to increase to 120 US$/tonne, then CHP production would not be profitable under any conditions and the feedstock should not be considered as a viable option. Moreover, these maps can help in the comparison of various feedstock options that may have similar prices, but with different energy potential. This makes it easier to see which option would be more profitable and stable in terms of production.

FIGURE 45.

Profitability Zones Maps sample

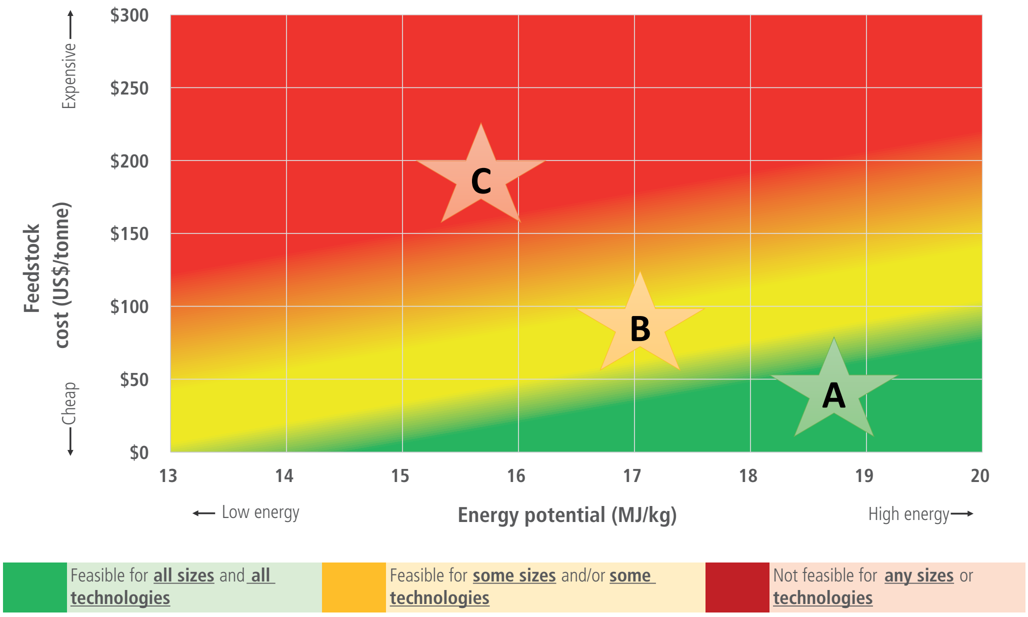
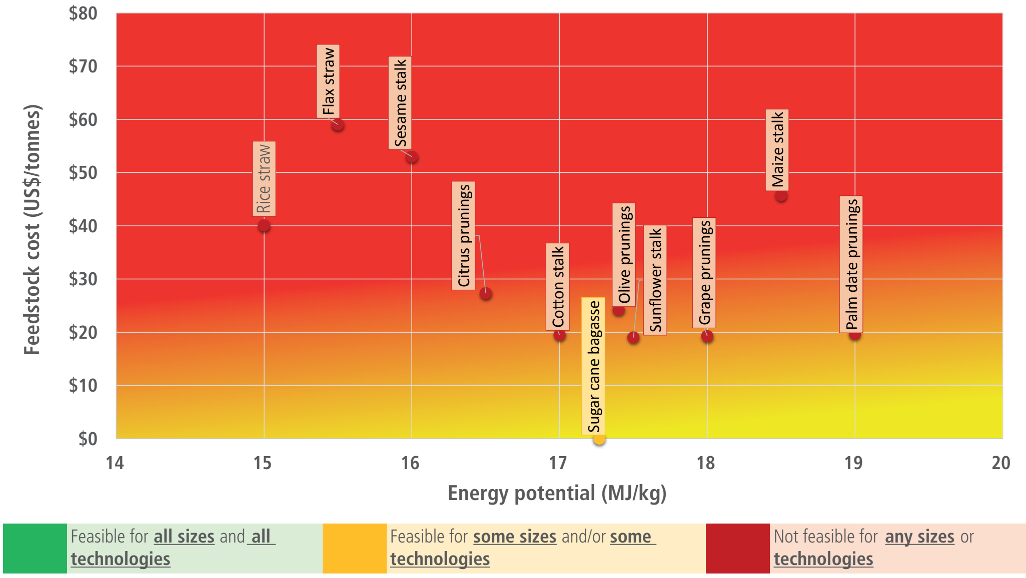


Figure 46 shows the Profitability Zones Map built for Scenario 1 with the Egyptian feedstock that was considered suitable and available for CHP production. From the information in Figure 44, the feedstock cost (US$/tonne) is shown on the y–axis and the energy potential (MJ/kg) is displayed on the x–axis. Figure 46 indicates that under current electricity and heat selling prices, the profitable production conditions are restricted to specific technologies (i.e. Tech 1), plant capacities and a maximum feedstock cost of around 10 US$/tonne As a result, there is no green zone and only a small portion of the chart is covered by the yellow zone, while the remaining part is enclosed in the red zone. Thus, under Scenario 1, the only Egyptian feedstock that may be profitable for energy production is sugar cane bagasse, due to its low cost.

FIGURE 46.

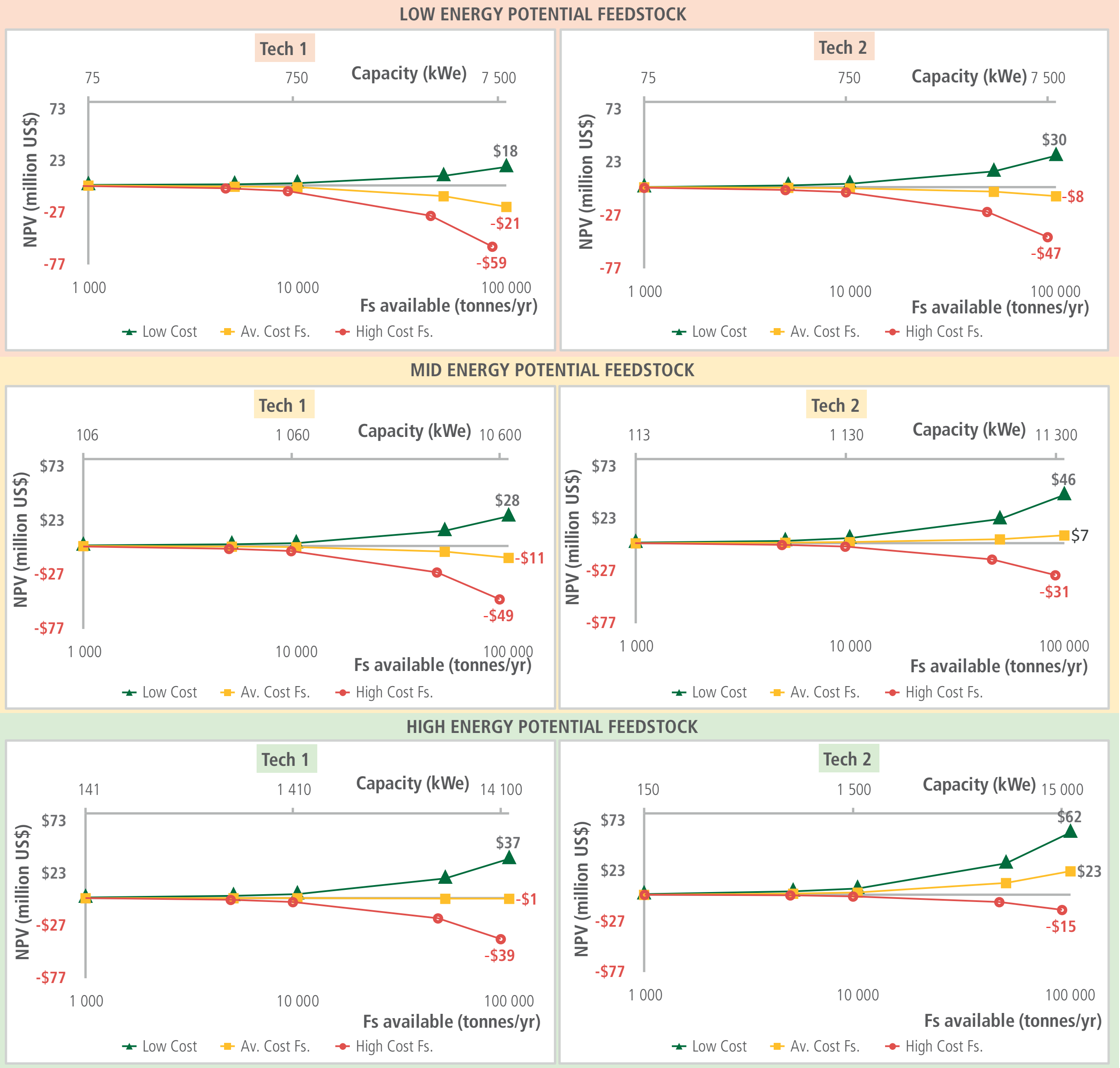
Profitability Zones Map – Scenario 1 (electricity price= 0.05 US$/kWh, heat price = 3.09 US$/GJ)



In Scenario 2, the electricity price is increased to 0.10 US$/kWh, which in turn increases the overall profitability of both Tech 1 and Tech 2. Thus, Figure 47 shows that energy production using low–cost feedstock (i.e. blue lines) may be profitable in all circumstances, regardless of feedstock type, technology or capacity. Additionally, energy production using average cost feedstock (i.e. green lines) may be profitable with Tech 2 when it involves mid and high energy potential feedstock.

FIGURE 47.

NPV (million US$) – Scenario 2



In the light of results from Figure 47, Table 19 displays the price ceiling for feedstock given the technology used and energy potential of that feedstock for Scenario 2. Compared with Scenario 1, the prices for Tech 2 have increased and these competitive prices can now be offered to biomass producers. Moreover, Tech 1 options can also be considered in the analysis.

TABLE 19.

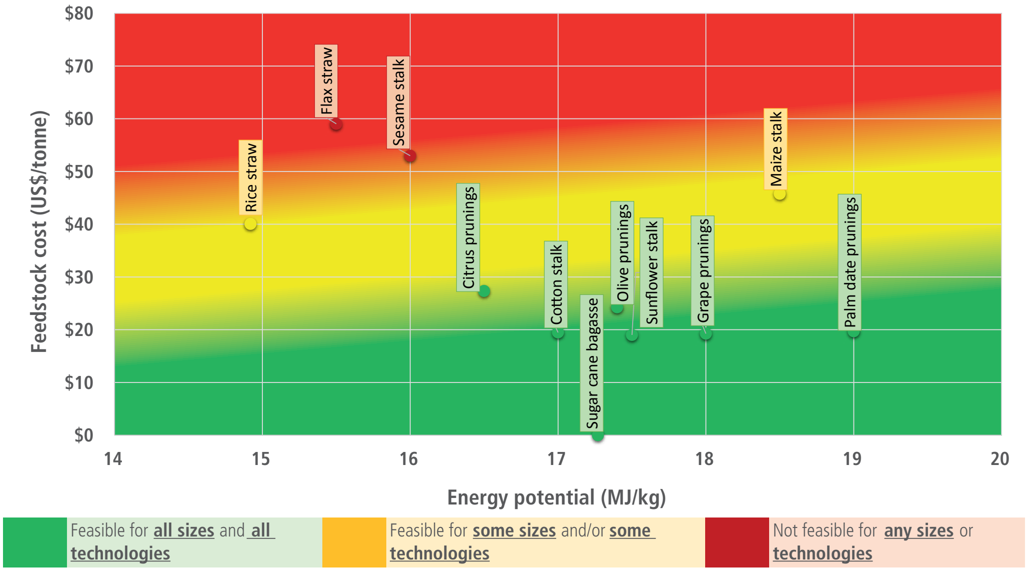
Maximum acceptable feedstock prices – Scenario 2

ENERGY POTENTIAL (MJ/kg)	MAX FEEDSTOCK PRICE (US$/tonne)	
	Tech1	Tech2
<13	US$25	US$41
<15	US$29	US$48
<17	US$31	US$51
<19	US$37	US$61

Figure 48 shows the Profitability Zones Map for Scenario 2. It presents a different situation from Scenario 1, as all three zones appear and a total of seven options fall within the green area. As a result, it is likely that energy projects based on these feedstock, with their current collection costs, will be profitable. Moreover, energy producers can perhaps pay for feedstock in the green area and, under certain production conditions, pay for the feedstock in the yellow area. The two feedstock located within the yellow area – rice straw and maize stalk – could be considered potential options for energy production. However, the calculated high collection costs reduce the flexibility of such options, as increasing the feedstock price and/or reducing electricity prices might threaten the economic sustainability of these projects.

FIGURE 48.

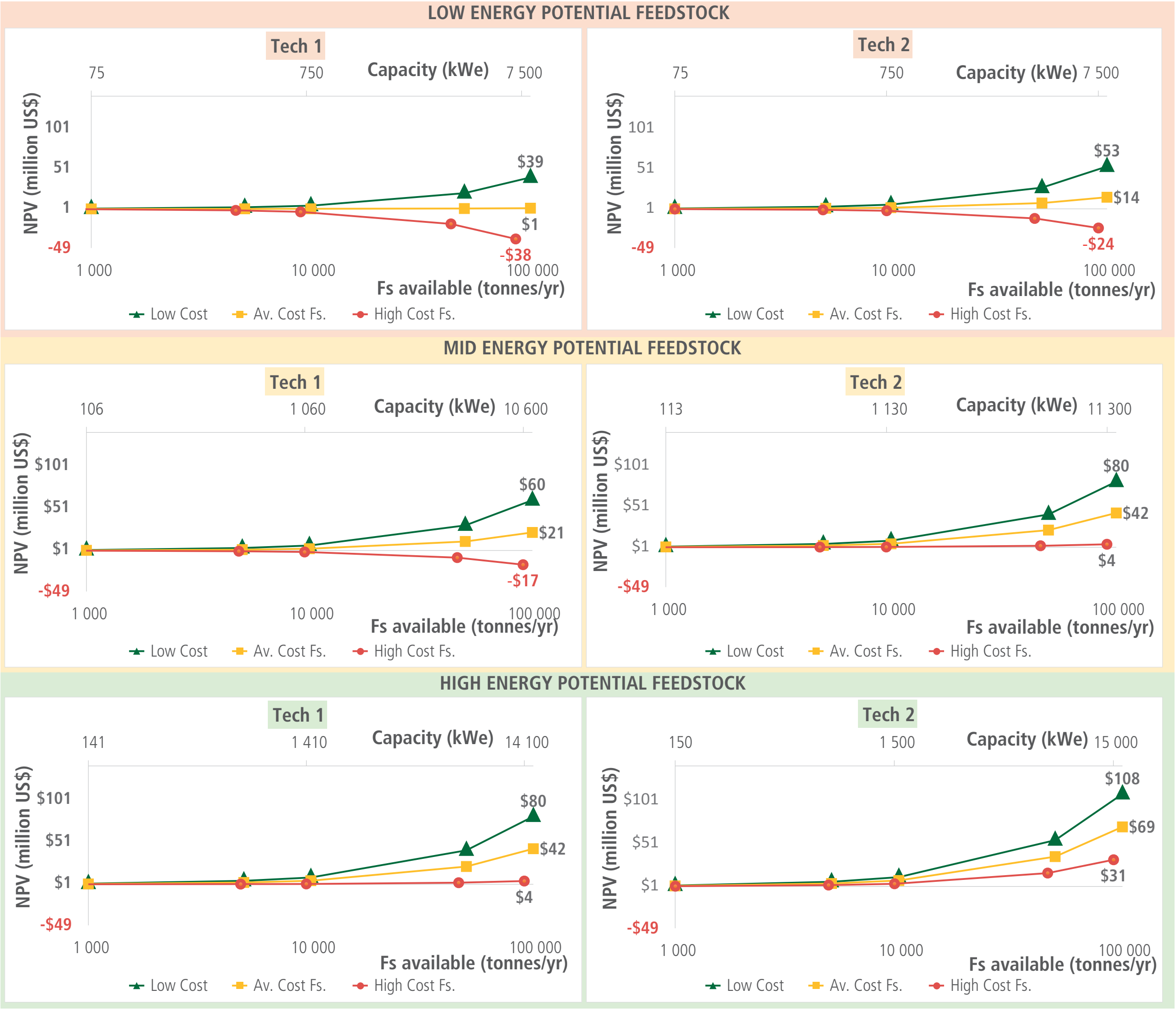
Profitability Zones Map – Scenario 2 (electricity price= 0.10 US$/kWh, heat price = 3.09 US$/GJ)



In Scenario 3, the electricity price is increased to 0.15 US$/kWh (Figure 49). Due to this 200 percent increment in the price of electricity, a high positive NPV for Tech 1 and Tech 2 is obtained. In this scenario, mid and high energy potential feedstock can now reach a positive NPV over the whole range of feedstock costs (i.e. 0–80 US$/tonne).

FIGURE 49.

NPV (million US$) – Scenario 3



Given the results from Figure 49, the price ceiling for the feedstock has dramatically increased and now ranges from 54 to 107 US$/tonne depending on the technology used and the feedstock energy potential (see Table 20).

TABLE 20.

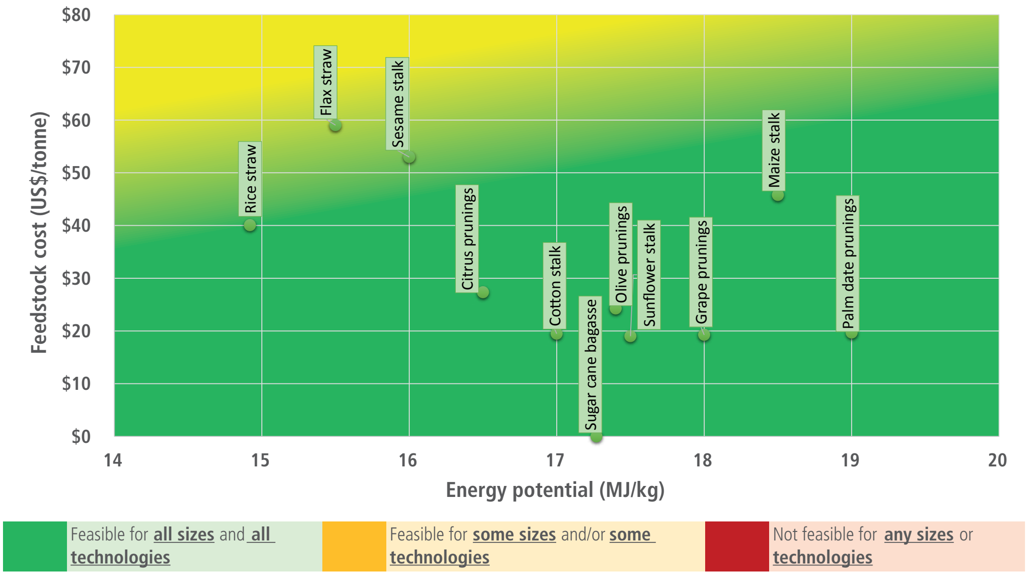
Maximum acceptable feedstock prices – Scenario 3

ENERGY POTENTIAL (MJ/kg)	MAX FEEDSTOCK PRICE (US$/tonne)	
	Tech1	Tech2
<13	US$54	US$73
<15	US$63	US$84
<17	US$67	US$90
<19	US$80	US$107

The Profitability Zones Map built for Scenario 3 (Figure 50) shows a very positive scenario for energy producers, since all of the Egyptian feedstock options identified as available and suitable for energy production may be profitable for Tech 1 and Tech 2, at all plant sizes. Compared with the other scenarios, bioenergy plants have much more flexibility under Scenario 3. This is due to the fact that even if there are increases in the cost of electricity or feedstock, the price ceiling is so high that it provides bioenergy plants with an increased buffer.

FIGURE 50.

Profitability Zones – Scenario 3 (electricity price= 0.15 US$/kWh, heat price = 3.09 US$/GJ)

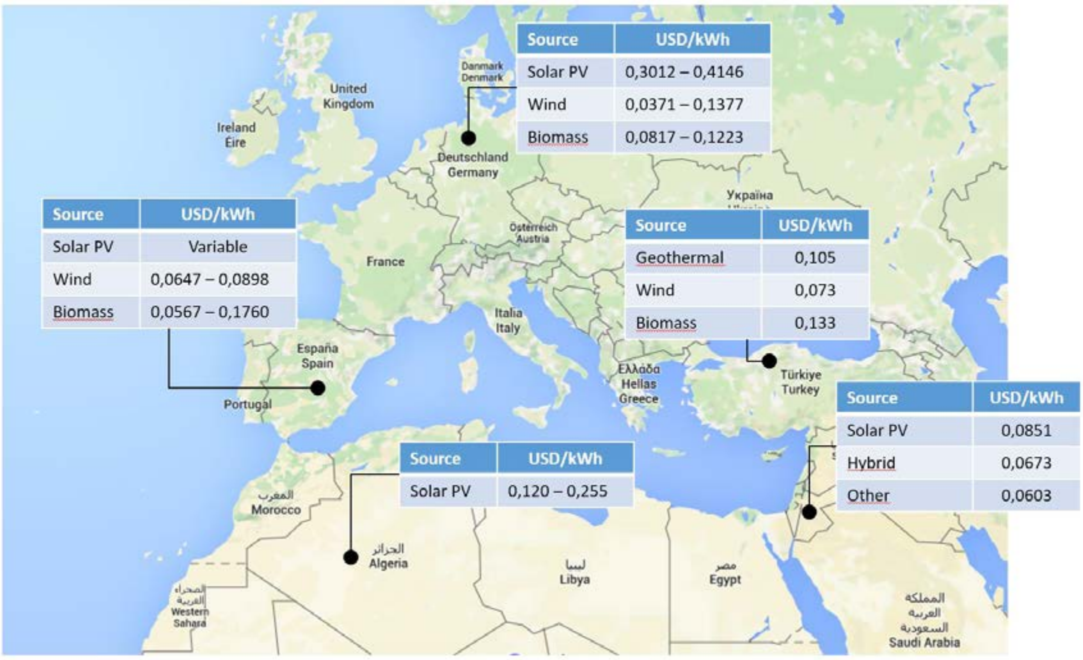


These results demonstrate the effects that different premium levels (Scenario 2 and 3) might have on the profitability of biomass–based electricity production when compared with the initial tariff level (Scenario 1). The initial tariff level assessed is the current electricity price paid by consumers (Scenario 1, 0.05 US$/kWh). However, this price means that biomass–based electricity producers will not receive a number of incentives and benefits. Therefore, two price increments are also examined (Scenario 2: 100 percent increase compared with Scenario 1 and Scenario 3: 200 percent increase compared with Scenario 1), which are potential premiums that can be obtained by biomass–based electricity producers.

From the point of view of a CHP producer, the best option is Scenario 3, since it has the highest potential profitability, while the current electricity price (Scenario 1) is the least appealing one. Nevertheless, any incentive or promotion strategy, such as a Feed–in–Tariff (FiT) with a premium, will ultimately be paid by the consumers. Yet the main objective of such policies is to find strategies that minimize public costs (Haas *et al.*, 2004). Thus, a high FiT with a premium would affect the final consumers, which would create problems at the other end of the spectrum.

FIGURE 51.

Summary of feed–in tariffs for renewables



Source	USD/kWh
Solar PV	0,3012 – 0,4146
Wind	0,0371 – 0,1377
Biomass	0,0817 – 0,1223

Source	USD/kWh
Solar PV	Variable
Wind	0,0647 – 0,0898
Biomass	0,0567 – 0,1760

Source	USD/kWh
Geothermal	0,105
Wind	0,073
Biomass	0,133

Source	USD/kWh
Solar PV	0,0851
Hybrid	0,0673
Other	0,0603

Source	USD/kWh
Solar PV	0,120 – 0,255

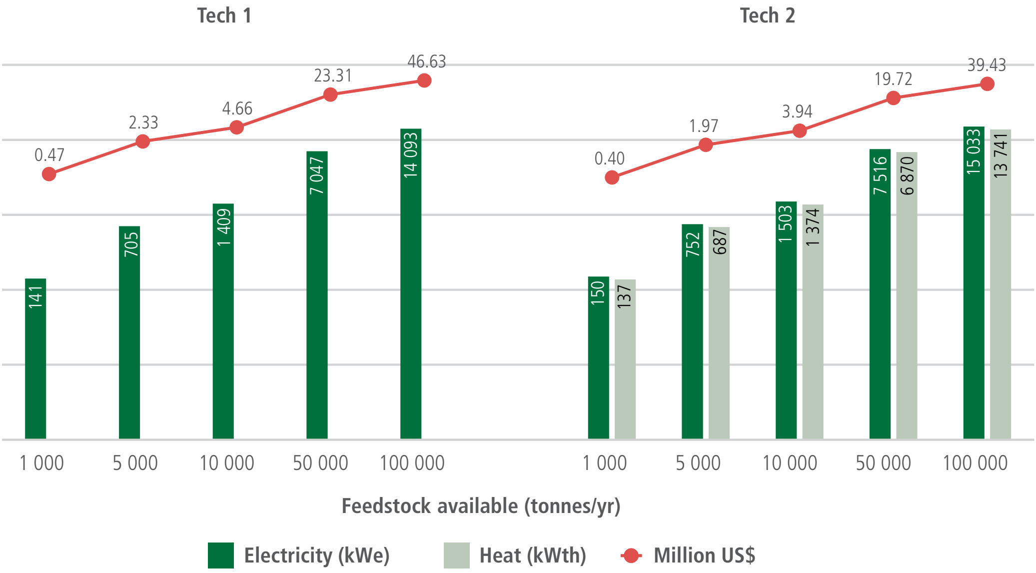
Source: Based on (Couture et al., 2010)

Therefore, a win–win situation would be a price closer to the one used in Scenario 2, which is fair for both producers and consumers. In fact, the FiT proposed by the Council of Ministers for Egypt in decision number 5/10/15/4 dated 28/10/2015 is 0.92 EGP/kWh (equivalent to 0.11 US$/kWh). Moreover, the FiTs in the region averaged around 0.113 US$/kWh in 2010 (Figure 52) (Couture *et al.*, 2010), which is a price in agreement with the projected FiT for Egypt and the suggested value found in this study.

The results also show that when it comes to potential profitability, Tech 2 always has an advantage over Tech 1. Aside from the credits obtained from the selling of heat, differences in total thermal efficiencies can explain this advantage. First, CHP systems use fuel more efficiently due to the fact that these systems have better total thermal efficiencies than conventional bioelectricity systems (Rincón *et al.*, 2014a). Second, since less fuel is required in a CHP system to meet the same energy production rates, the equipment used is also smaller, since the inputs are of a lesser quantity. Due to this reduction in equipment size and fuel amount, the operative and capital costs make CHP technologies a more cost–effective option. Figure 52 shows an example of a comparison of energy production capacities of heat and electricity for Tech 1 and Tech 2 for a mid–energy potential feedstock. The feedstock is better utilized with CHP (Tech 2), as can be seen from the higher electricity production rates, the additional heat produced and the comparatively lower capital investment costs for energy production when using the same feedstock quantities. Costs of CHP plants used in this study are around 2 600, in agreement with the values reported in the literature for similar CHP plants (C2ES, IRENA, 2012).

FIGURE 52.

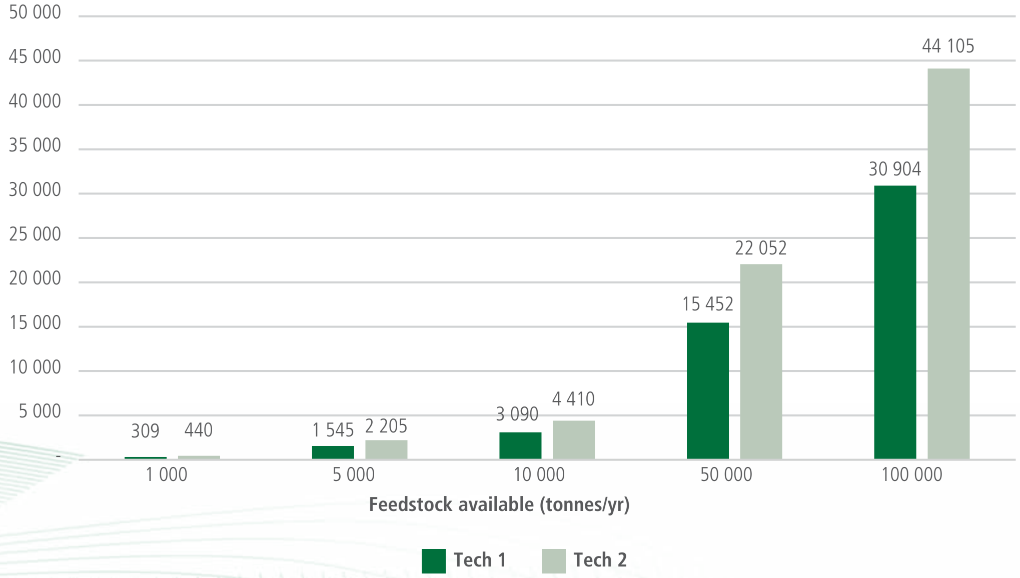
Comparison of capital investments for Tech 1 and Tech 2 for a mid–energy potential feedstock



To contextualize the effect of this difference in energy production, the number of households that can potentially be supplied using each technology was estimated. Figure 53 shows that CHP plants can supply 29 percent more households than conventional bioelectricity production (Tech 1), when using the same feedstock amount. Thus, CHP (Tech 2) is a more appealing option for investors in Egypt, considering potential revenues, lower capital investment and higher energy generation rates.

FIGURE 53.

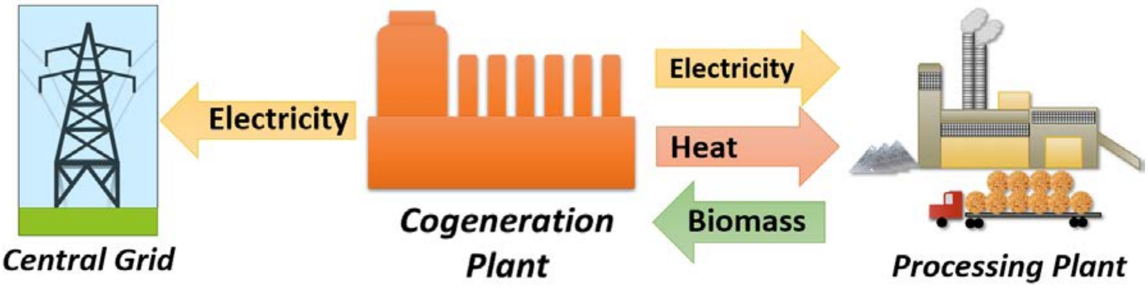
Households potentially supplied with Tech 1 and Tech 2



The most profitable scheme for CHP production, under the assessment conditions, would be CHP facilities attached to processing plants, where the biomass used as fuel is locally produced and available for direct use in cogeneration plants at low cost. CHP plants in turn supply heat and electricity to the processing plant. Large electricity surpluses are usually obtained and can be directly sold to the central grid at the FiT (Figure 54). This stand–alone plant could also make additional investments that would allow for the conversion of heat into cool via a cooling system (i.e. absorption chillers), granting a year–round market.

FIGURE 54.

Suggested production scheme for CHP from direct biomass in Egypt



Based on these results, a number of recommendations are provided to attain profitable production in CHP plants:

- Use high efficiency technologies for the production of heat and electricity;
- Stronger preference for feedstock with high energy potentials;
- Stronger preference for Technology 2;
- Stronger preference for feedstock located at processing plants, as this may reduce feedstock costs;
- Prioritize configuration of CHP plants attached to industrial factories, which would buy heat and electricity directly, reducing distribution costs; and
- Use the heat surplus and convert into cool using a cooling system.

Considering the most profitable processing conditions and the feedstock amount available, a list of suggested feedstock for Egypt under Scenario 2 is summarized in Table 21. This summary also lists the collection costs calculated under the current country situation and the energy potential of the feedstock. Additional feedstock could be included or excluded from this list, depending on improvements in collection methods that reduce collection costs, changes in alternative uses that create competitive markets for feedstock or accessibility issues.

TABLE 21.

List of promising feedstock for CHP direct combustion production in Egypt

CROP RESIDUE TYPE		LOCATION	COLLECTION STATUS	COLLECTION COST (US$/ tonne)	ENERGY POTENTIAL (MJ/kg)
Maize	stalk	Field–spread	Collected	$46	17.95
Rice	straw	Field–spread	Collected	$40	14.92
Citrus	prunings	Field–spread	Collected	$27	16.93
Olive	prunings	Field–spread	Collected	$24	16.93
Palm date	prunings	Field–spread	Collected	$20	18.60
Cotton	stalk	Field–spread	Collected	$19	17.09
Grape	prunings	Field–spread	Collected	$19	17.75
Sunflower	stalk	Field–spread	Collected	$19	17.19
Sugar cane	bagasse	Processing	Collected	$0	17.27

Taking into account the profitable production conditions determined above, the list of promising feedstock from Table 21, and the feedstock availability by governorate (estimated in the natural resources assessment), Table 22 was created. This table shows the plant electricity capacities for each governorate. Feedstock selected include: maize stalk, rice straw, citrus prunings, olive prunings, palm date prunings, cotton stalk, grape prunings, sunflower stalk and sugar cane bagasse.

TABLE 22.

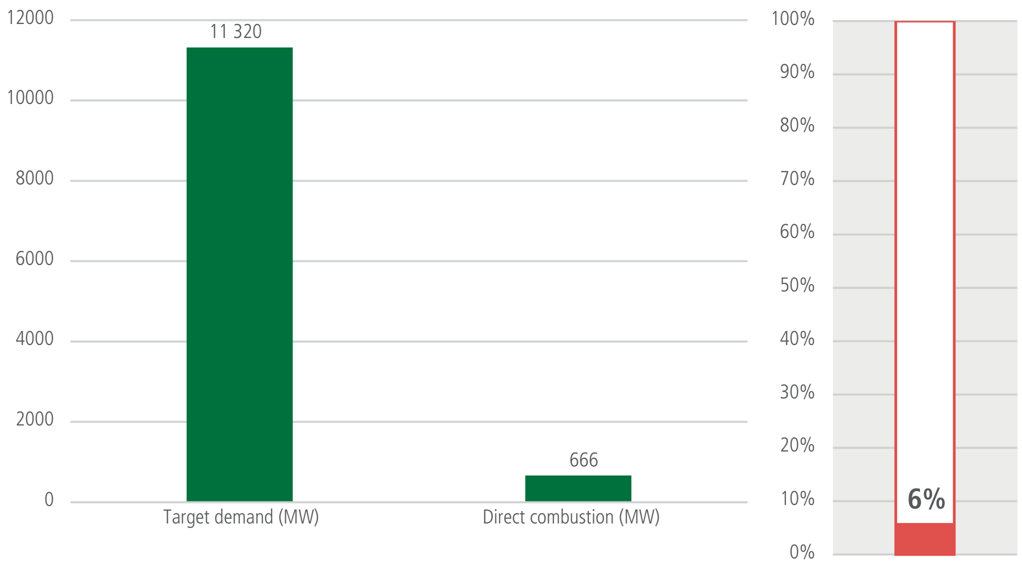
Combined production capacity in governorates – CHP direct combustion

ELECTRICITY CAPACITY (MW)										
GOVERNORATE	CITRUS PRUNINGS	OLIVE PRUNINGS	PALM DATE PRUNINGS	COTTON STALK	SUGAR CANE BAGASSE	GRAPE PRUNINGS	SUNFLOWER STALK	MAIZE STALK	RICE STRAW	TOTAL CAPACITY GOVERNORATE (MW)
Sharkia	4.88	0.3	0.6	9.3	-	0.3	-	31.2	24.5	71.03
Dakahlia	0.37	-	-	9.9	0.2	0.8	-	9.8	42.7	63.64
Behera_ Noubaria	17.33	4.49	4.04	22.3	0.3	12.9	1.4	-	-	62.82
Kafr_El Sheikh	0.36	-	0.99	21.1	-	-	-	9.2	28.8	60.50
Menia	0.40	-	-	0.3	14.0	3.0	0.4	33.3	-	51.37
Qena	-	-	-	-	42.7	-	-	7.2	-	49.91
Aswan	-	-	2.0	-	29.8	-	-	1.9	-	33.70
Gharbia	1.04	-	-	3.7	0.5	1.6	-	10.7	13.9	31.51
Menoufia	3.08	0.6	-	0.7	-	1.8	-	24.9	-	31.09
BeniSuef	0.51	0.3	-	1.4	0.2	0.8	-	26.1	-	29.28
Luxor	-	-	-	-	22.8	-	-	2.9	-	25.71
Fayoum	0.45	2.7	0.2	4.0	0.2	0.2	0.5	16.7	-	24.97
Suhag	-	-	0.1	0.4	5.8	-	-	18.2	-	24.47
Assuit	1.03	0.41	0.67	1.1	0.6	0.4	0.4	19.0	-	23.64
Giza	1.25	1.0	1.9	-	0.7	0.9	0.1	9.7	-	15.57
Qalyoubia	3.14	-	-	-	0.2	-	-	8.2	1.5	13.09
Ismailia	2.59	2.3	0.4	0.3	-	0.3	-	4.8	0.5	11.29
North Sinai	0.41	4.6	3.5	-	-	-	-	-	-	8.60
Damietta	-	-	0.3	1.5	-	-	-	-	6.7	8.41
Alexandria	-	-	-	1.3	-	-	-	5.6	-	6.88
New Valley	0.28	0.47	2.65	-	-	-	-	2.2	0.7	6.30
Matruh	-	3.97	1.24	-	-	0.6	-	-	-	5.79
Port Said	-	-	-	0.5	-	-	-	-	2.1	2.60
South Sinai	-	1.58	-	-	-	-	-	-	-	1.58
Cairo	-	1.09	0.15	-	-	-	-	-	-	1.24
Suez	0.33	0.3	-	-	-	-	-	-	-	0.66
Red sea	-	-	-	-	-	-	-	-	-	-
TOTAL	37.45	24.11	18.74	77.8	118	23.6	2.8	241.6	121.4	665.65

These results show strong potential to produce bioenergy in Egypt. Given the potentially available feedstock amount, plant capacities were calculated. The top five most promising feedstock for CHP production are: maize stalk, rice straw, sugar cane bagasse, cotton stalk and citrus prunings. The governorates of Sharkia, Dakahlia, Behera_Noubaria, Kafr El Sheikh, Menia, and Qena are the most promising areas that could establish the largest profitable plants. The combined production capacity of all governorates in Egypt reaches 666 MWe, which could cover 6 percent of the 11 320 MWe target demand for renewable energies (see Figure 55). This contribution might be considered important in a country where most agricultural production is concentrated in a narrow section around the Nile River.

FIGURE 55.

Contribution to the 2020 energy target demands



Biogas to electricity results

The above results were obtained for feedstock that can be burned directly to produce energy in CHP plants. However, some feedstock cannot be directly burned, because either its water content is too high or ashes produced during combustion are too abundant. In these specific cases, the most technically appropriate solution is to upgrade such feedstock into a superior energy form. In this sense, biogas production presents a convenient option to extract the energy potential contained in wet biomass. Technical production conditions previously identified also apply for CHP production from biogas, with slight modification as shown in Figure 56. This scheme takes advantage of feedstock with high availability that could not otherwise be converted into bioenergy, due to its high water content, and transforms it into useful energy as heat and electricity.

FIGURE 56.

Suggested production scheme for CHP from biogas in Egypt

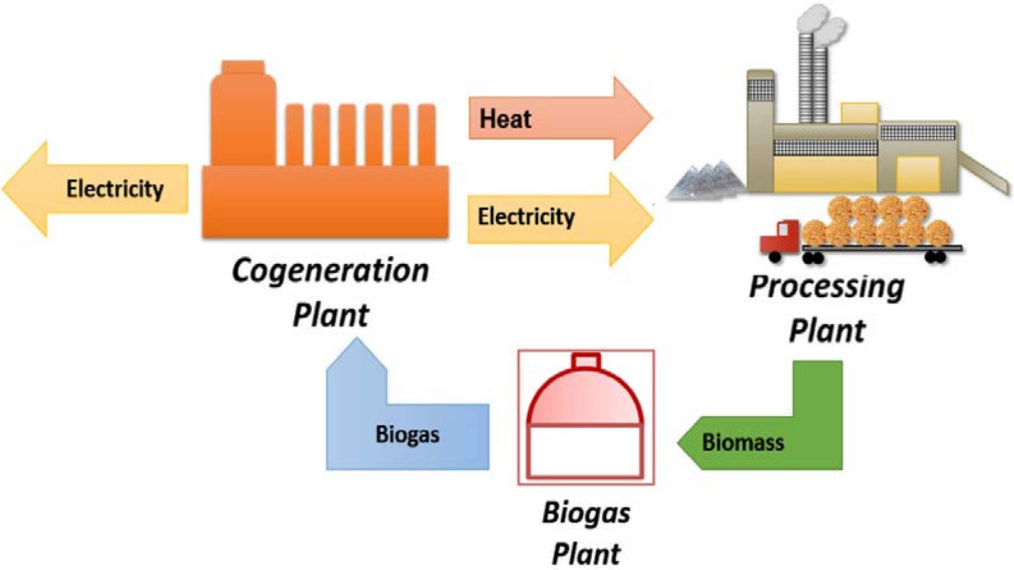


FIGURE 57.

Break–even analysis – Biogas to CHP

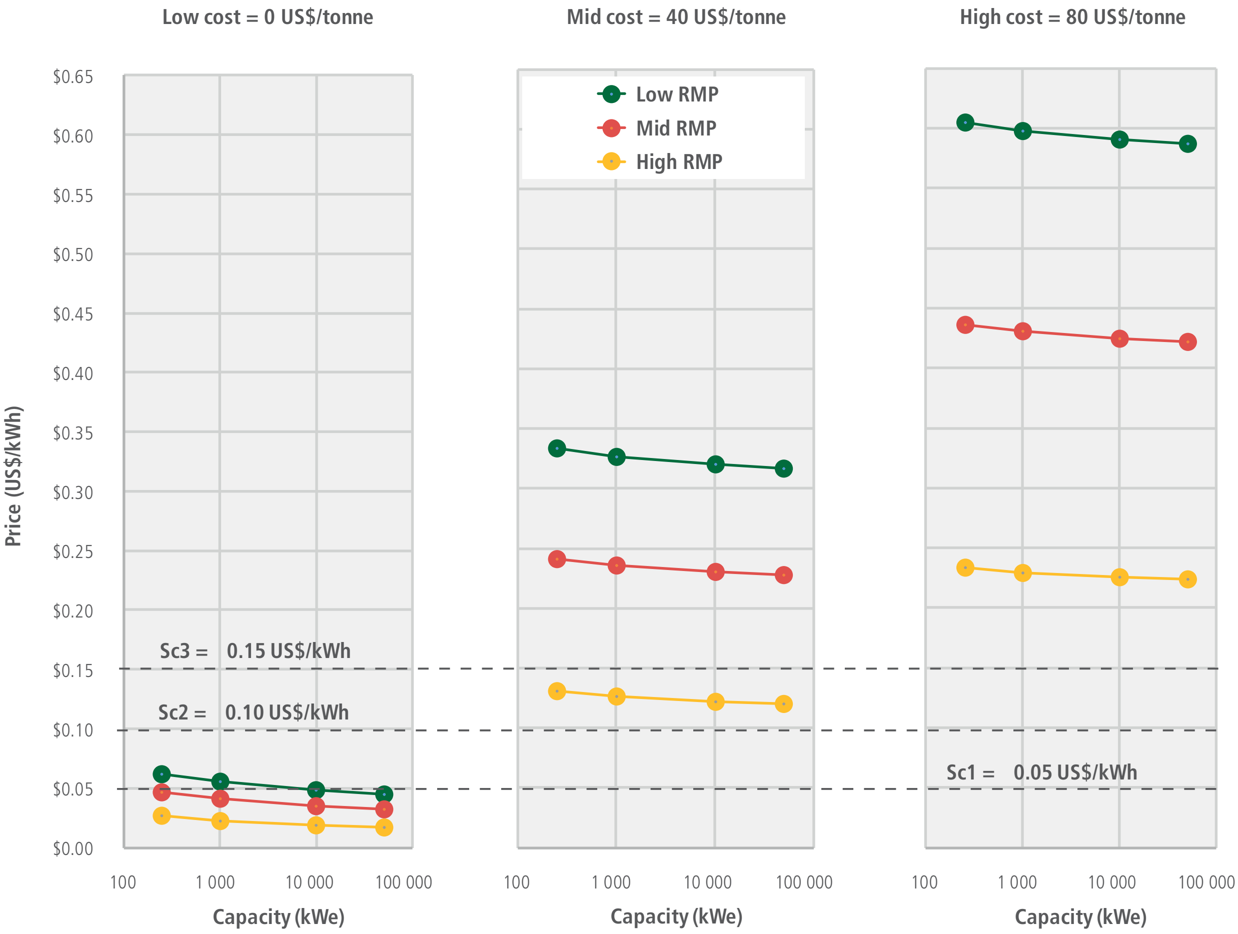


Figure 57 presents the BEP obtained at different feedstock costs of CHP plants based on biogas and introduces a new variable on the x–axis, the Realistic Methane Potential (RMP). The RMP was used as an indicator to identify the potential to produce biogas, considering production conditions such as hydraulic retention time (HRT), total volatile solids (S0), ultimate methane yield (B0), maximum specific growth rate of microorganisms (μm), and the kinetic factor (K). The combination of all these elements is considered in Hashimoto's equation (Equation 3) and are a good indicator of the realistic production rates of methane of a specific feedstock under a given set of conditions (Hashimoto *et al.*, 1981).

Equation 3

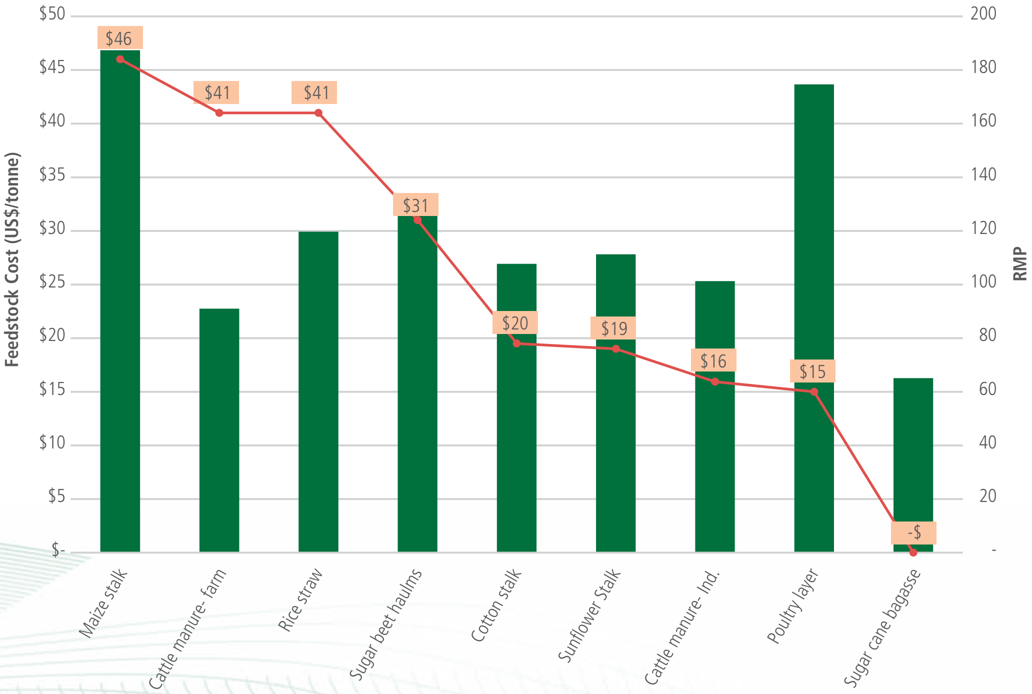
$$RMP = \frac{B_0 \cdot S_0}{HRT}\left(1- \frac{K}{HRT \cdot \mu_M -1+K}\right) (20^{\circ}C < T < 60^{\circ}C)$$

Like the energy potential, the RMP has a remarkable effect on BEP for the biogas to electricity option, and feedstock with a higher potential to generate biogas should be the preferred option. Additionally, the BEPs show that it is not profitable to pay more than 40 US$/tonne for feedstock, even at the highest electricity price of 0.15 US$/kWh (Scenario 3).

Figure 58 summarizes the RMP and collection costs for feedstock identified as available and potentially suitable for biogas production according to the literature (Wellinger *et al.*, 2013; Drosg *et al.*, 2013; Paepatung *et al.*, 2009). This figure shows that the RMP is not directly related to collection costs, and that feedstock with higher RMP might have lower collection costs than those with a comparatively low RMP.

FIGURE 58.

Comparison chart for energy potential and estimated collection costs of feedstock selected for biogas to CHP



Profitability was again assessed under the three scenarios described in the previous section, for four nominal capacities of electricity production (250, 1 000, 10 000 and 50 000 kWe) from biogas. Unlike CHP direct combustion, plant sizes were predefined, as the fuel burned in CHP plants will always be biogas with a relatively homogenous composition across all considered feedstock. Therefore, changes in energy production as a result of changes in the energy potential of feedstock do not occur. Thus, the feedstock quality variable will depend on the RMP.

Figure 59 combines the NPV charts and Profitability Zones Map obtained for Scenario 1. This figure demonstrates that under an electricity selling price of 0.05 US$/kWh, only low–cost feedstock, at certain production scales and RMP, may be profitable. Therefore, only feedstock with a very high RMP (around 187) and a cost of less than 13 US$/tonne would be profitable at all plant sizes (see Table 23). Consequently, the Profitability Zones Map is almost entirely a red zone, and none of the feedstock identified as available and potentially suitable is profitable.

FIGURE 59.

NPV (million US$) and Profitability Zones Map – Scenario 1 (electricity price= 0.05 US$/kWh, heat price = 3.09 US$/GJ)

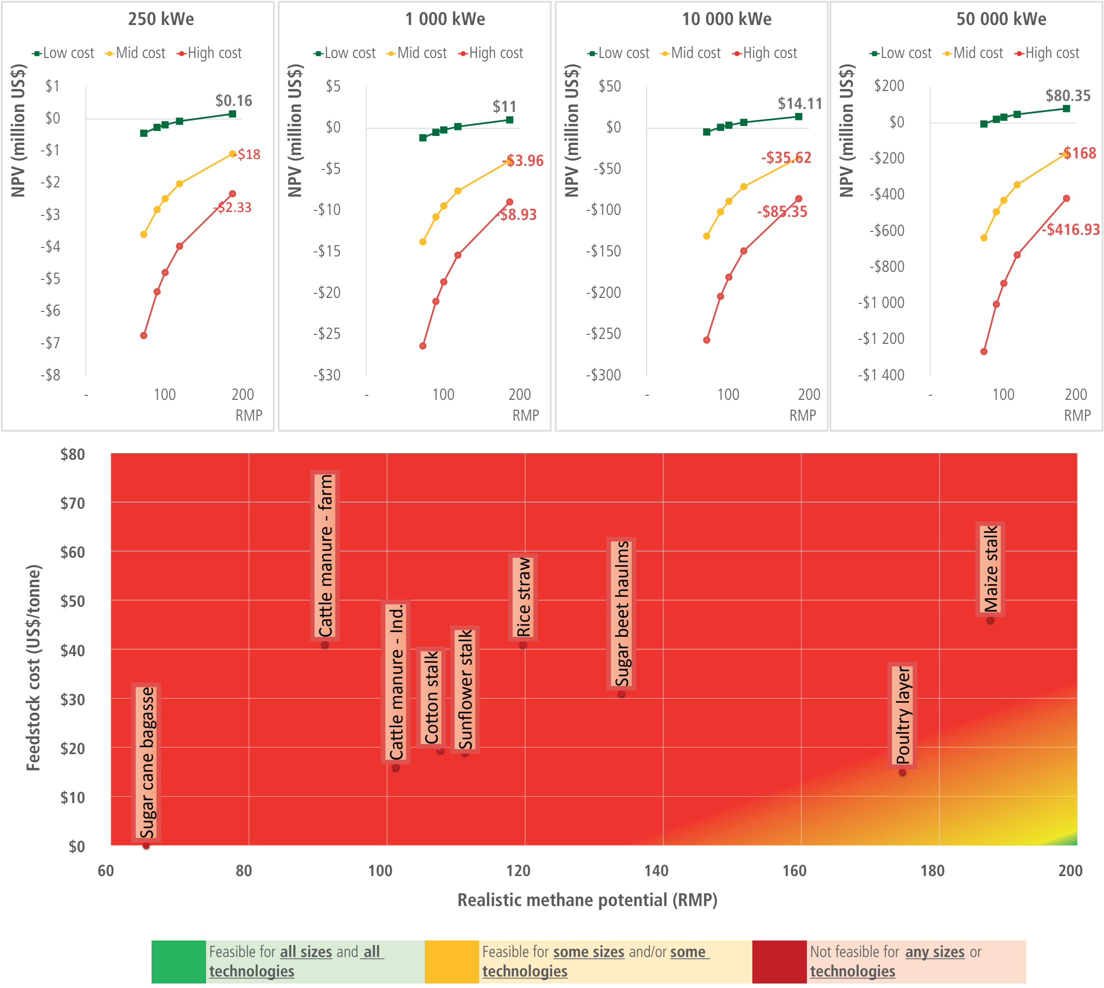


TABLE 23.

Maximum acceptable feedstock prices – Scenario 1

RMP	MAX FEEDSTOCK PRICE (US$/tonne)			
	250 kWe	1 000 kWe	10 000 kWe	50 000 kWe
<74	$0	$0	$0	$0
<91	$0	$0	$0	$2
<101	$0	$1	$4	$5
<120	$0	$1	$4	$5
<187	$5	$8	$11	$13

Figure 60 shows the results of an increase in the electricity price to 0.10 US$/kWh. With this, a number of feedstock are now considered as potentially profitable and displayed in the yellow and green zones in the Profitability Zones Map. Although the maximum feedstock price for the highest RMP ranges from 24 to 34 US$/tonne (see Table 24), all production scales may be profitable using appropriate feedstock with high RMP and low cost. Thus, under the Scenario 2 electricity price, sugar cane bagasse, cattle manure, cotton stalk and sunflower stalk qualified for yellow zone profitable conditions and poultry layers resulted as the most promising option.

FIGURE 60.

NPV (million US$) and Profitability Zones Map – Scenario 2 (electricity price= 0.10 US$/kWh, heat price = 3.09 US$/GJ)

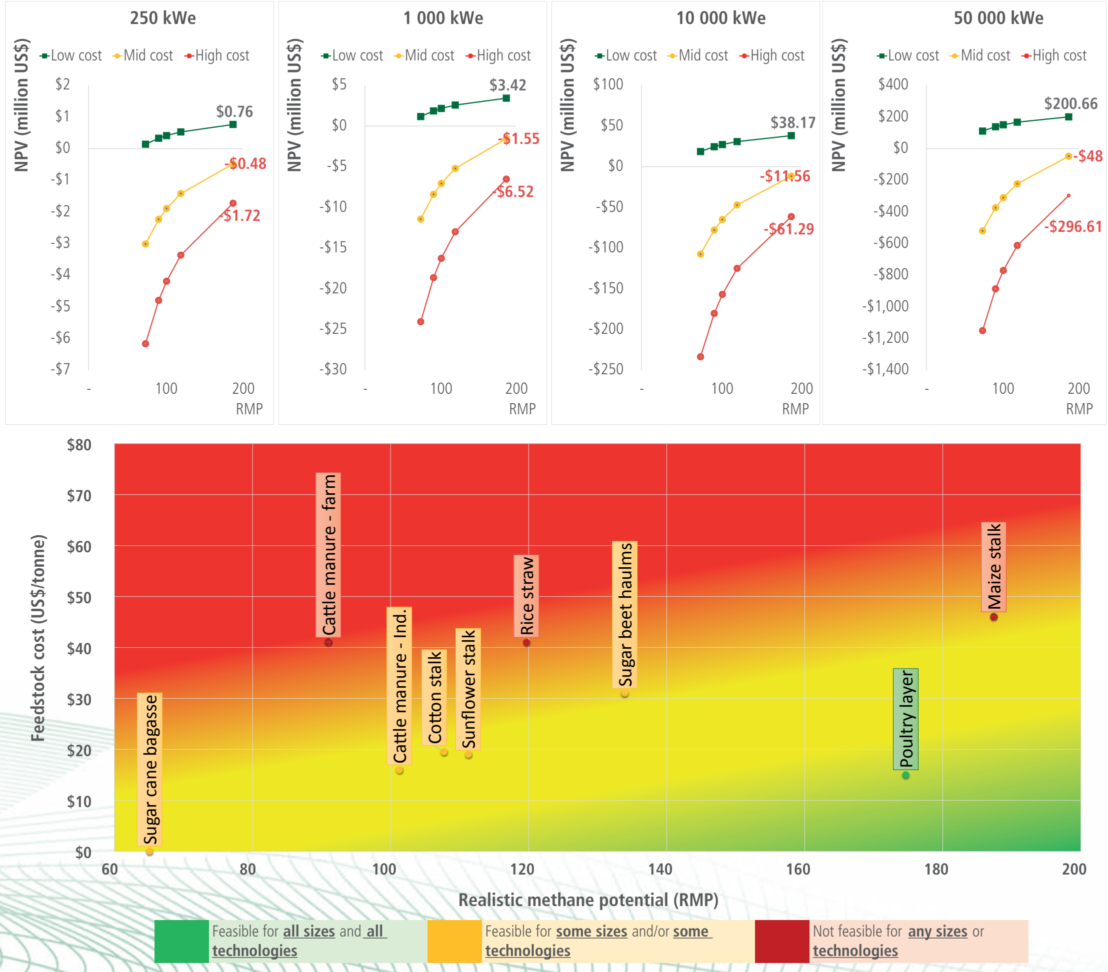


TABLE 24.

Maximum acceptable feedstock prices – Scenario 2

RMP	MAX FEEDSTOCK PRICE (US$/tonne)			
	250 kWe	1 000 kWe	10 000 kWe	50 000 kWe
<74	$1.8	$3.7	$5.9	$7.0
<91	$5.1	$7.2	$9.6	$10.8
<101	$10.8	$13.2	$15.9	$17.2
<120	$11.5	$14.0	$16.8	$18.2
<187	$24.5	$27.5	$30.7	$32.3

In the final scenario of the analysis, the electricity price increased to 0.15 US$/kWh and this in turn caused an increase of 37 percent in the maximum feedstock prices (see Table 25). Thus, the overall profitability also rose, so that a greater number of feedstock entered into the green zone, including: sugar cane bagasse, cattle manure, cotton stalk, sunflower stalk, sugar beet haulms and poultry layers (see Figure 61).

FIGURE 61.

NPV (million US$) and Profitability Zones Map – Scenario 3 (electricity price= 0.15 US$/kWh, heat price = 3.09 US$/GJ)

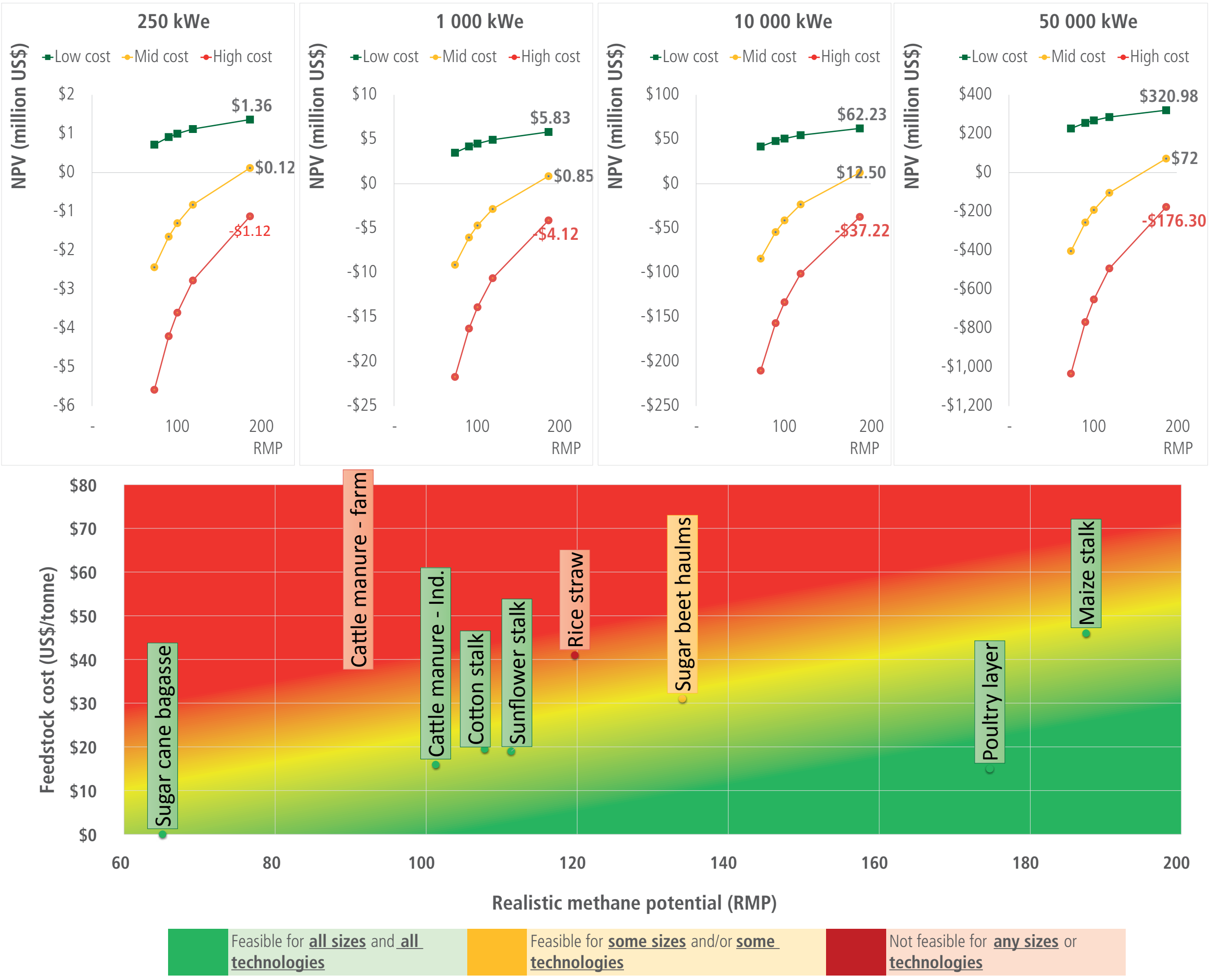


TABLE 25.

Maximum acceptable feedstock prices – Scenario 3

RMP	MAX FEEDSTOCK PRICE (US$/tonne)			
	250 kWe	1 000 kWe	10 000 kWe	50 000 kWe
<74	$9.1	$11.1	$13.3	$14.4
<91	$14.3	$16.4	$18.8	$20.0
<101	$23.0	$25.4	$28.1	$29.4
<120	$24.5	$27.0	$29.8	$31.2
<187	$43.9	$46.9	$50.1	$51.6

These results demonstrate that production conditions are even more stringent for CHP from biogas than for CHP from direct combustion, considering the calculated maximum feedstock prices and the changes in profitable production conditions. Thus, under the proposed FiT of 0.11 US$/kWh, electricity production using CHP from biogas would have restricted profitable production conditions, requiring feedstock with RMP larger than 120 and feedstock prices ranging between 1.8 and 32.3 US$/tonne. In this sense, larger plants would initially be more attractive, given the potential revenues and the number of households potentially supplied (see Figure 62). However, capital investment also needs to be considered.

FIGURE 62.

Number of households per plant size

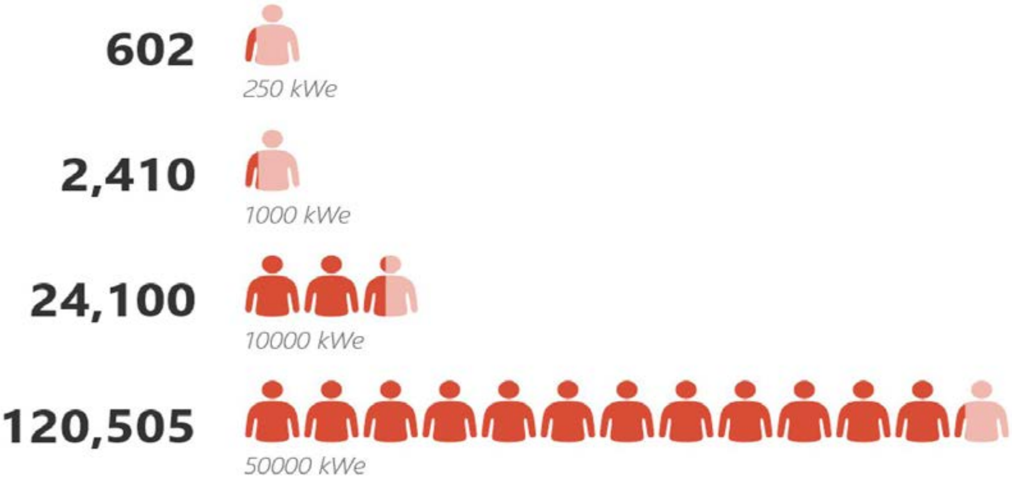
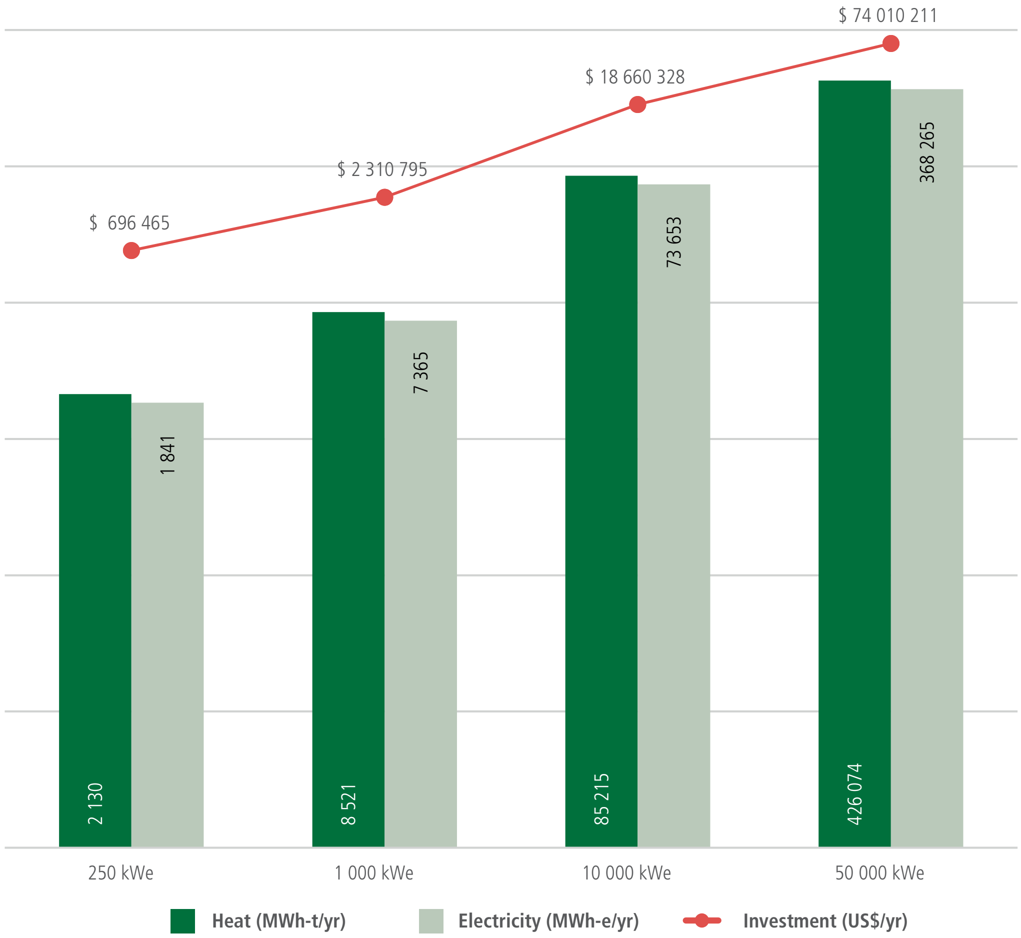


Figure 63 summarizes the investment needed for different electricity capacities, and the heat and electricity generated for each capacity.

FIGURE 63.

Capital investments for different plant sizes

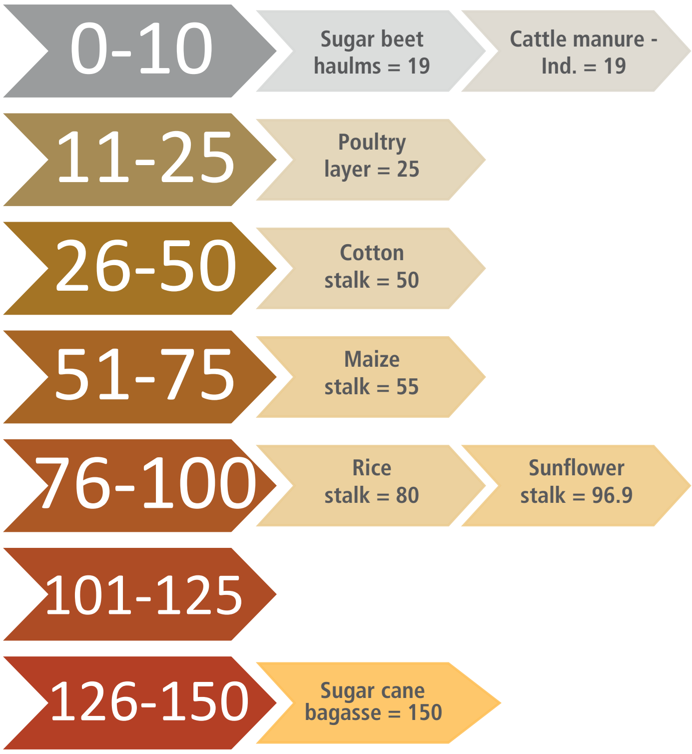


The last stage of this analysis applies the above profitable production conditions to a list of promising feedstock for biogas in Egypt. Considering the accessibility criteria described in the livestock residues analysis, quantities and feedstock available for biogas production were identified. In the case of cattle manure, it was assumed that only those farms rearing more than 50 heads of cattle would be able to collect manure for biogas industries. Then, manure available per governorate was factored by the share of such farms. In the case of poultry layers, the amounts identified as available were so low that they were not enough to be profitable. Additionally, some of these residues (cotton stalk and sugar cane bagasse) have greater potential in CHP based on direct combustion, so are not considered for CHP–based biogas. Thus far, only cattle manure and sunflower stalks are considered for biogas production.

Furthermore, CHP plants based on biogas should use feedstock efficiently and minimize its cost, in order to be economically sustainable over time. A suitable year–round operation for biogas plants is codigestion, since it combines multiple substrates, but also reduces operation costs by allowing for the combination of low– and high–cost feedstock (Holm–Nielsen *et al.*, 2009). In order to understand at what ratio different substrates can be mixed in codigestion systems, one rule of thumb is to take into account the C:N ratio of components. During anaerobic digestion, the different chemical components of feedstock (i.e. C, H, N, O) are selectively used by the different digestion bacteria, with the specific ratios of organic matter (carbon) to nitrogen being particularly important to perform optimal digestion and avoid inhibitory effects. In this sense, C:N ratios higher than 23:1 might result as unsuitable for optimal digestion, while ratios below 10:1 might inhibit the digestion process (Marchaim, 1992).

FIGURE 64.

C/N Ratios of feedstock analysed in this study



Based on the abovementioned criteria, and aiming to minimize the feedstock cost and excluding certain feedstock – those with low available quantities or with more profitable uses in direct combustion – the following substrates were identified for the production of biogas: cattle manure, cattle manure with sunflower stalk and sugar beet haulms. Table 26 calculates the potential electricity capacity per governorate for these feedstock.

TABLE 26.

Combined production capacity in governorates – Biogas to electricity

ELECTRICITY CAPACITY (MW)				
GOVERNORATE NAME	**BIOGAS FROM CATTLE MANURE**	**BIOGAS FROM CATTLE MANURE + SUNFLOWER STALK**	**BIOGAS FROM SUGAR BEET HAULMS**	**TOTAL COMBINED CAPACITY (MW)**
Qena	12.00	0.00	0.00	12.00
Behera	9.70	0.43	1.12	11.25
Sharkia	10.20	0.00	0.13	10.33
Menoufia	9.50	0.00	0.02	9.52
Qalyoubia	6.80	0.01	0.01	6.83
Menia	5.50	0.79	0.16	6.46
Suhag	6.40	0.00	0.00	6.40
Dakahlia	4.70	0.00	1.63	6.33
Kafr–El Sheikh	1.70	1.10	2.91	5.71
BeniSuef	3.10	1.32	0.72	5.15
Red sea	0.10	3.37	1.29	4.75
Gharbia	4.00	0.10	0.27	4.37
Fayoum	1.90	0.89	0.47	3.26
Ismailia	2.30	0.06	0.14	2.49
New Valley	2.40	0.00	0.00	2.40
Giza	1.10	0.41	0.69	2.19
Assuit	2.20	0.03	0.00	2.23
Aswan	1.00	0.02	0.00	1.02
Alexandria	0.50	0.19	0.14	0.84
Damietta	0.60	0.00	0.00	0.60
Port Said	0.10	0.00	0.40	0.50
Suez	0.40	0.00	0.00	0.40
Cairo	0.00	0.29	0.02	0.30
Matruh	0.10	0.05	0.00	0.15
Luxor	0.10	0.00	0.00	0.10
North Sinai	0.00	0.00	0.00	0.00
South Sinai	0.00	0.00	0.00	0.00
TOTAL	86.40	9.05	10.12	105.57

The combined electricity capacity from CHP based on biogas is 106 MW. When this 106 MW is added to the 666 MW that may be obtained through CHP based on direct combustion, the total reached is 772 MW. This potential would be able to cover 7 percent of the 11 320 MW renewable energy target (see Figure 65), supply more than 2.2 million households and avoid 2.9 million tonnes CO_2eq/year.

FIGURE 65.

Combined production capacity

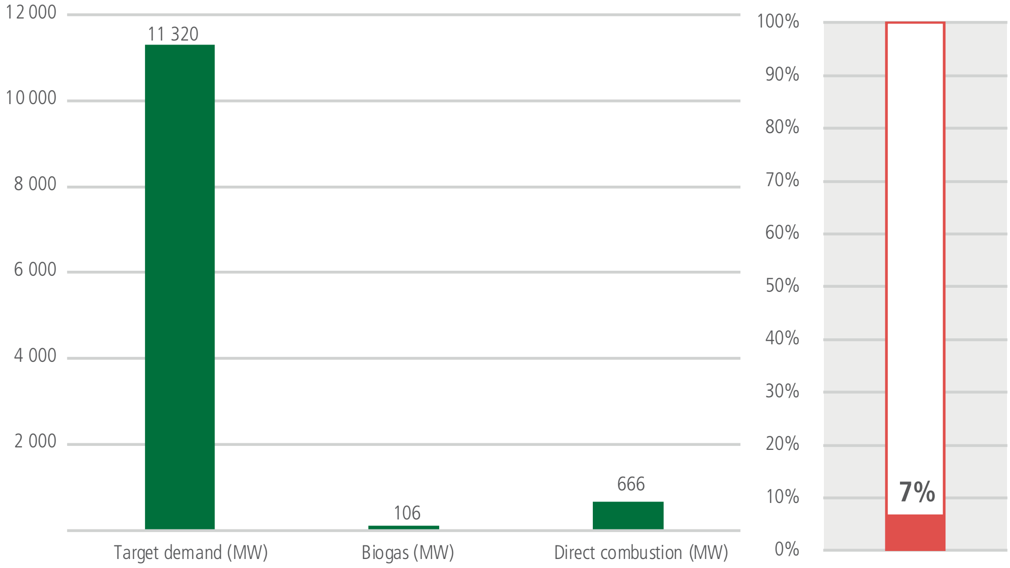
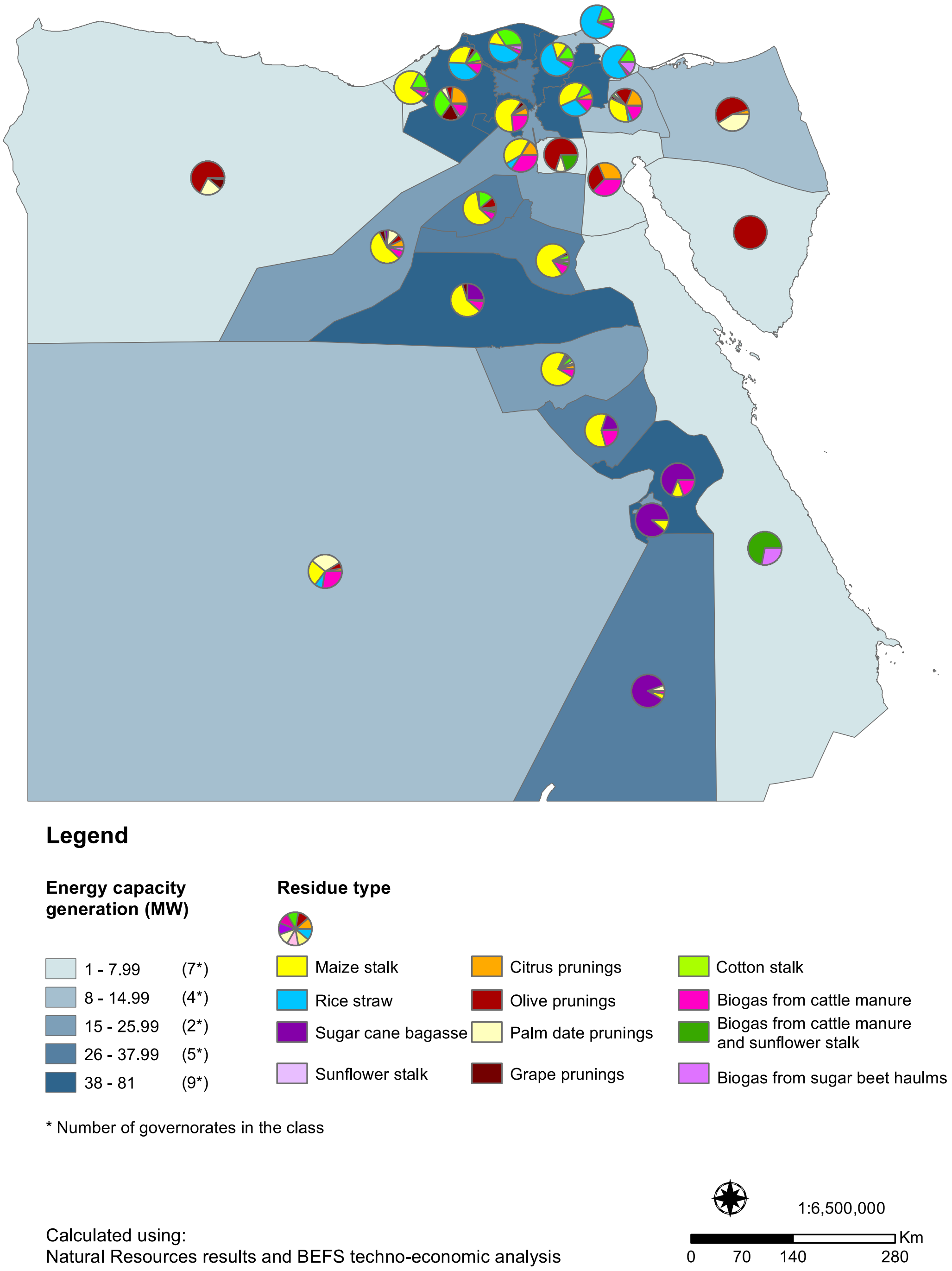


Figure 66 offers a better understanding of the potential location of CHP plants based on biogas or direct combustion. From this figure, it can be observed that around the Nile River area, where the country is more industrialized, higher generation capacities can be obtained. The feedstock with the highest potential for energy generation in Egypt are rice straw in the north, maize stalk in the middle and sugar cane bagasse in the south. Conversely, in the less populated desert areas, combined production capacity is comparatively low, and mainly supplied by woody residues (i.e. prunings). These results indicate the importance of taking the level of industrialization into consideration in any final discussions on where different combinations of biomass and bioenergy technologies might be more effective.

FIGURE 66.

Total potential electricity generation using CHP technologies



Calculated using:
Natural Resources results and BEFS techno-economic analysis

Briquette and pellet results

The second energy end use alternative considered in this study is using biomass residues as an option to supply heating and/or cooking demands in Egypt. The techno–economic potential of converting sustainable biomass residues into bioenergy was therefore assessed.

The results obtained are presented in a similar manner to previous sections, first taking into account BEP, followed by profitability (a calculation using the NPV), Profitability Zones Maps and maximum feedstock prices.

The most critical variables affecting the viability of this type of project are the energy potential of feedstock, feedstock cost, market of products and the selected densification option (briquettes or pellets).

As explained in previous sections, the BEA for briquettes and pellets compares the BEP at different energy levels and production quantities. Additionally, this is parametrized at various energy potentials and feedstock cost levels. In the case of briquettes and pellets, figures show discontinuities at the initial points of each BEP line. These represent differences between manual production (dots) and mechanized production (lines). Thus, it was possible to compare the two most common technological modifications found in densification industries: cold press and hot press. Finally, prices are presented in energy units (US$/GJ) to allow for a direct comparison of briquette/pellet prices versus their market prices and competitive fossil fuel prices (in this case, liquefied petroleum gas (LPG)).

FIGURE 67.

Break–even analysis – Briquettes

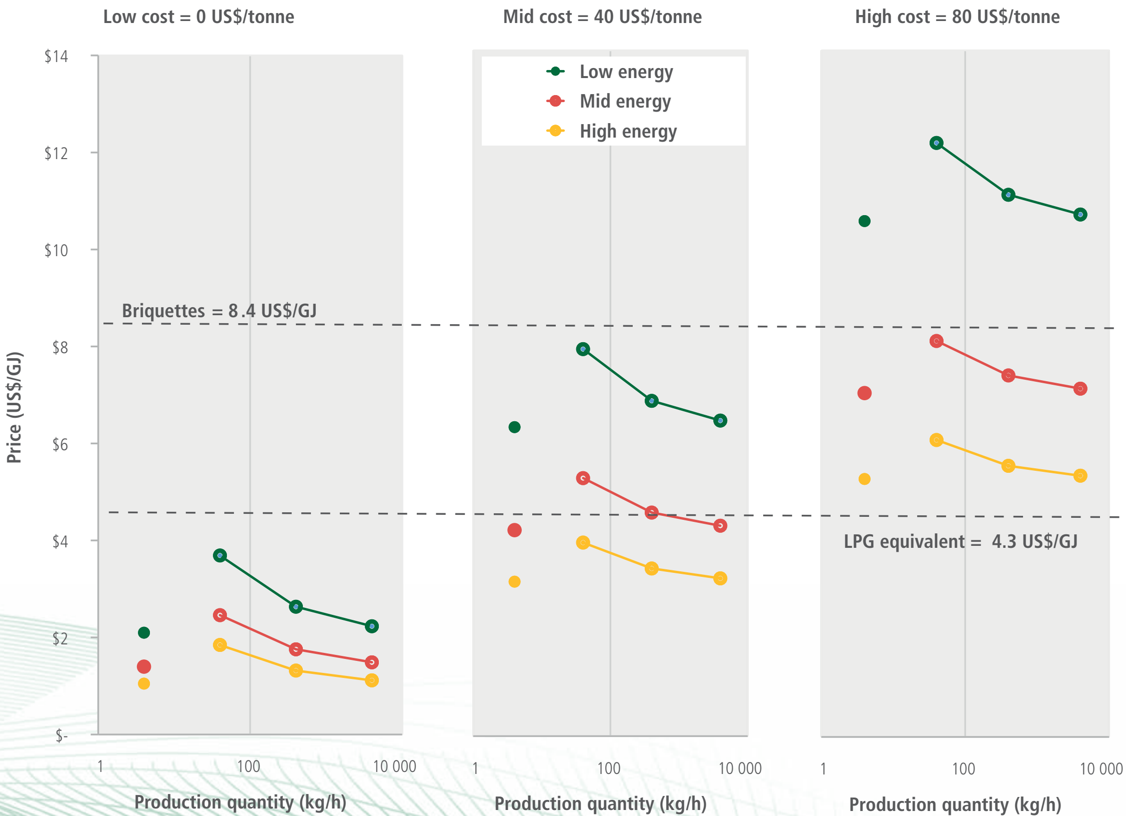
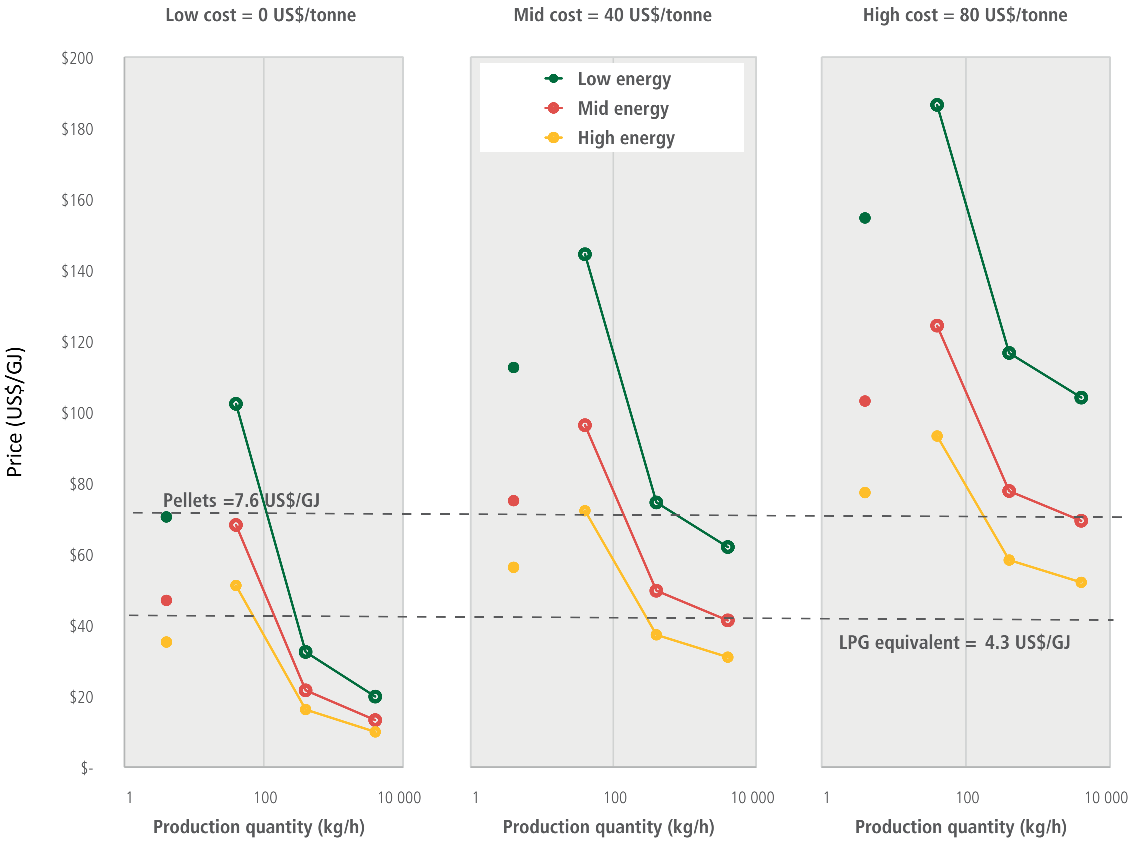


Figure 67 compares the BEP for briquettes with their current market price (8.4 US$/GJ) and the LPG equivalent price (4.3 US$/GJ). These results demonstrate that due to high market prices for briquettes, there is potential for profitable production, even when considering high cost feedstock. This holds true as long as briquette producers use mid– and high–energy potential feedstock. Similarly, Figure 68 reveals similar conclusions when comparing pellets' BEP with their market prices. Again, the results show that it is possible to achieve profitable pellet production using high–cost feedstock with high energy potential. However, unlike briquettes, only a limited set of plant sizes are profitable. Additionally, when compared, manual production (dotted values) presented lower BEPs than mechanized production (lines) of briquettes, at all operation levels. Conversely, for pellets, the BEPs for manual production are higher than those obtained for mechanized production, when looking at large–scale operations. These results suggest that a small–scale operation using cold press technology is more competitive when using briquette technology, whereas a large–scale operation using hot press technology is more competitive when using pellet technology.

FIGURE 68.

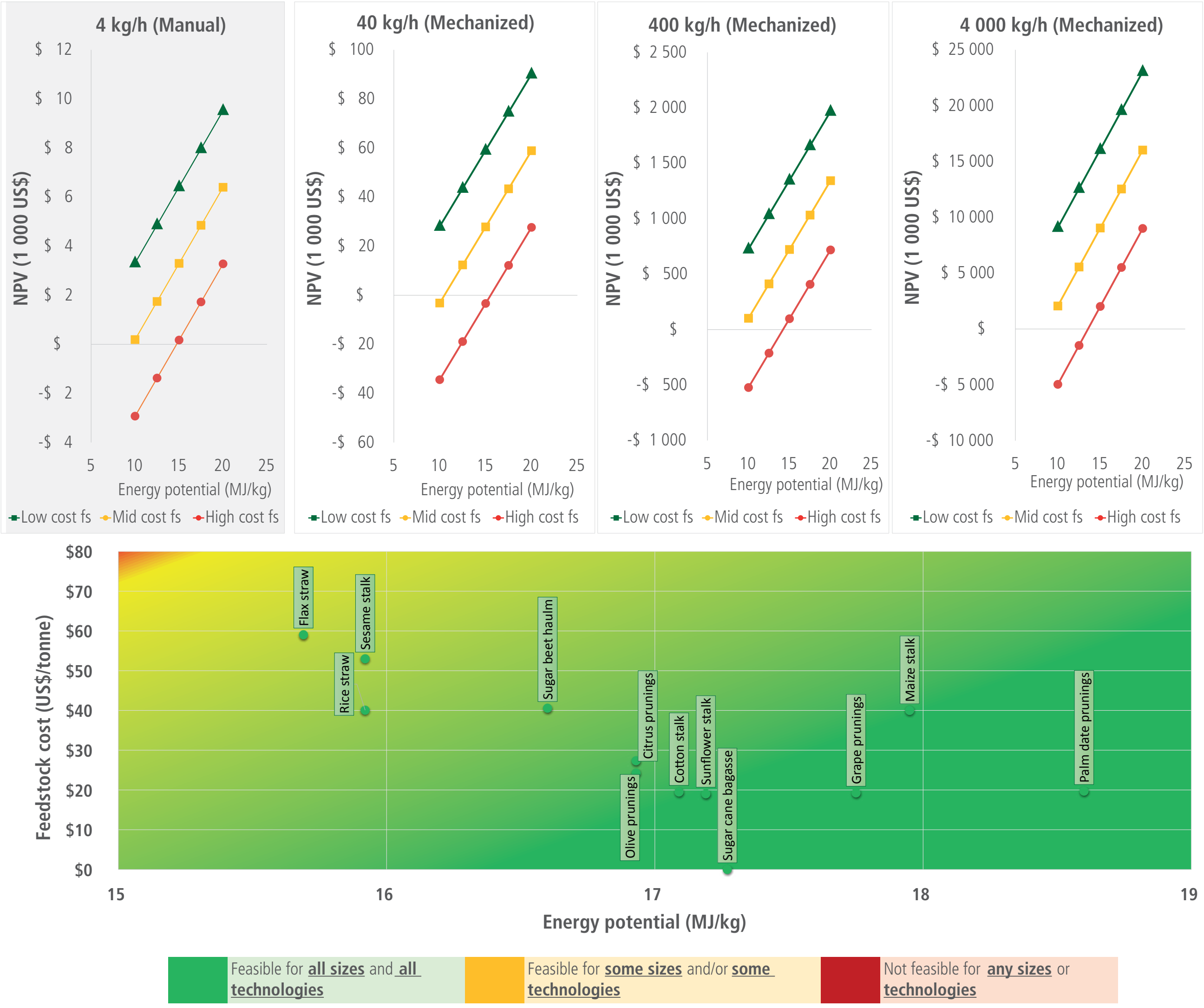
Break–even analysis – pellets



The results above suggest that there is a competitive advantage for briquettes compared with pellets, which is explained by the higher market price of the first option. However, a more detailed analysis using a profitability indicator, such as NPV, is necessary.

FIGURE 69.

Profitability Zones Map – Current reference price (briquettes price = 140 US$/tonne = 8.4 US$/GJ)



The NPV analysis for briquettes at the market price in Egypt is summarized in the top part of Figure 69. The results show that there is potential for significant profitability for most of the energy potentials, feedstock costs and plant sizes, due to the high market price of briquettes. In the bottom part of the figure, the Profitability Zones Map is dominated by the green zone, showing that all the Egyptian feedstock is promising. Given the current briquette market price, the maximum feedstock price that can be paid to biomass producers is highly competitive and ranges from 54 to 116 US$/tonne (see Table 27).

TABLE 27.

Maximum acceptable feedstock prices – Briquettes at market price

ENERGY POTENTIAL (MJ/kg)	MAX FEEDSTOCK PRICE (US$/tonne)			
	4 (kg/h)	40 (kg/h)	400 (kg/h)	4 000 (kg/h)
<13	$69	$54	$64	$67
<15	$82	$67	$77	$81
<17	$64	$72	$82	$86
<19	$116	$101	$111	$115

Similarly, Figure 70 displays the profitability calculated for pellets at the current market price. These results demonstrate that the potential profitability of pellets is different from that of briquettes. Despite the high market price for pellets, small–scale production (4 and 40 kg/h) is not profitable over time, resulting in negative NPV values. Nevertheless, the NPV charts for large–scale pellet plant sizes (400 and 4 000 kg/h) show positive profitability.

FIGURE 70.

Profitability Zones Map – Current reference price (Pellets price = 119 US$/tonne = 7.6 US$/GJ)

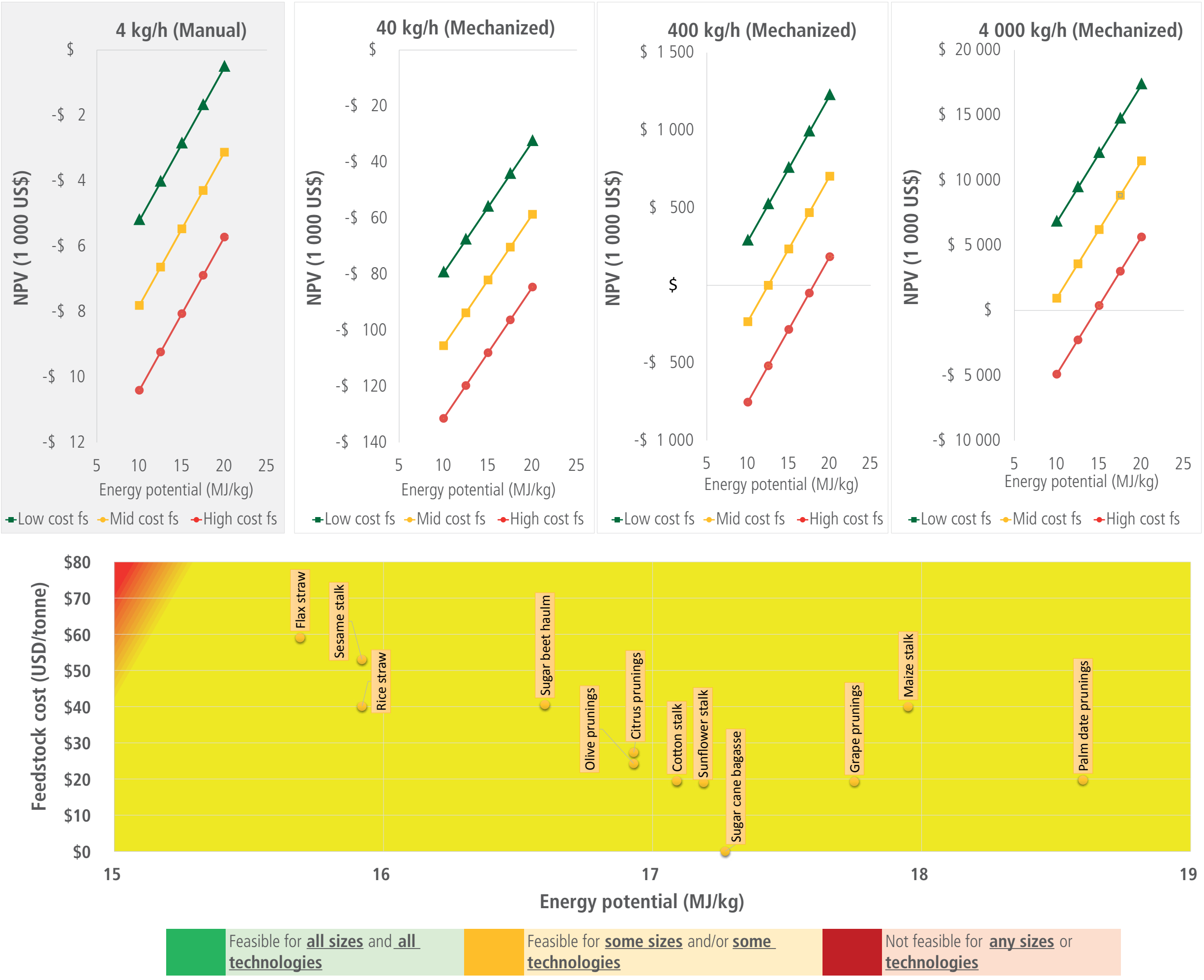


Figure 70 also shows that the Profitability Zones Map is primarily yellow, with a very small zone shaded in red. This can be explained by the fact that although all feedstock options may seem promising, most of them are only profitable under certain plant sizes. Another indicator of this is the wide range of maximum feedstock prices, which now vary from 0 to 119 US$/tonne (Table 28).

TABLE 28.

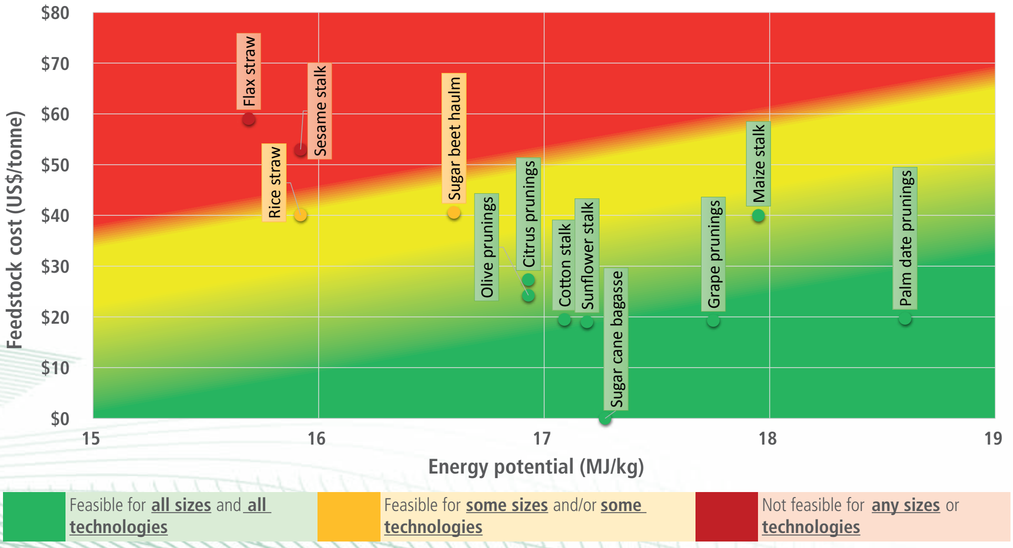
Maximum acceptable feedstock prices – Pellets at market price

ENERGY POTENTIAL (MJ/kg)	MAX FEEDSTOCK PRICE (US$/tonne)			
	4 (kg/h)	40 (kg/h)	400 (kg/h)	4 000 (kg/h)
<13	$0	$0	$44	$68
<15	$0	$0	$58	$83
<17	$0	$0	$62	$88
<19	$0	$0	$94	$119

It is important to contextualize these results. The values obtained show that briquettes and pellets could be promising high–income sectors. However, it is important to consider that reference prices used until now are market ones, where briquettes and pellets are not intended to supply the daily energy requirements of consumers. Instead, they are considered as high–end goods (used, for example, on barbeques). This implies that there is a limited market for any new briquette and pellet production from biomass to be used as high–end goods. The next possible market is therefore using briquettes and pellets as replacement fuels. Previously, it was stated that LPG would probably be the fuel to replace, given its high subsidies and extended use throughout the country (Ministry of Finance, 2015; James, 2015). In the light of this observation, the next level of analysis uses LPG as the reference price, and the energy equivalent price of LPG is calculated so that it can be compared with briquettes and pellets.

FIGURE 71.

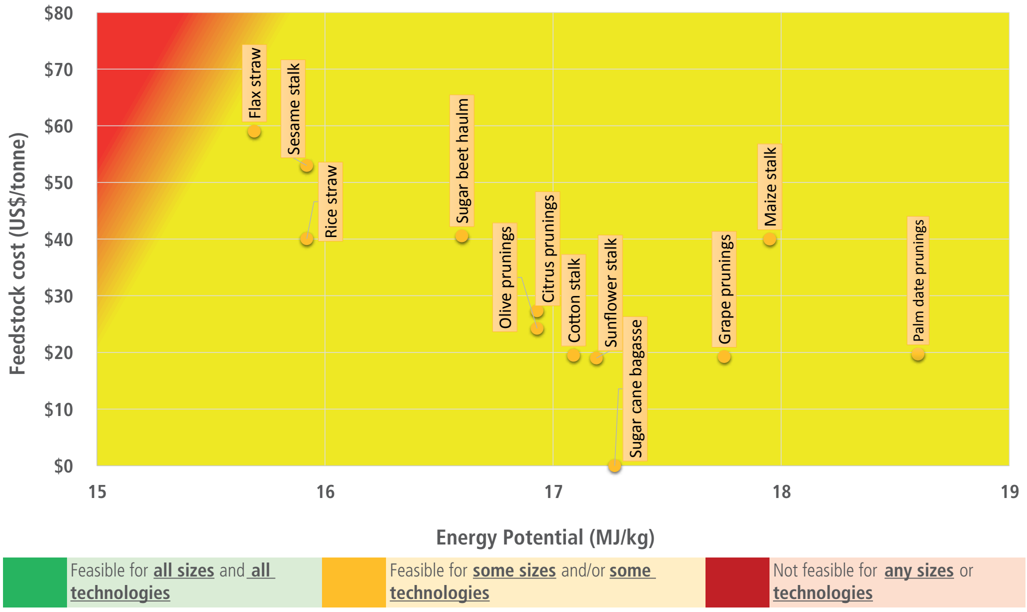
Profitability Zones Map – Briquettes replacing fossil fuels (LPG price = 8 LE/cylinder = 4.3 US$/GJ)



When comparing the BEP results for briquettes and pellets as a potential replacement for LPG (see Figure 67 and Figure 68), it can be observed that although profitable production conditions are positive, they are now more restricted. As a consequence of this, Figure 71 and Figure 72 show reductions in the green (briquettes only) profitability zones and noteworthy increments in the yellow zones (both briquettes and pellets).

FIGURE 72.

Profitability Zones Map – Pellets replacing fossil fuels (LPG price = 8 LE/cylinder = 4.3 US$/GJ)



For briquettes, the abovementioned effect caused a reduction in the number of promising feedstock. However, for pellets, none of the feedstock moved into the red zone and instead most of the feedstock fell into the yellow zone. These results can be better explained in Table 29 and Table 30, which show that in a scenario where briquettes and pellets replace LPG in Egypt, the maximum feedstock price would range from 18 to 62 US$/tonne for briquettes, and from 0 to 93 US$/tonne for pellets. Thus, in the case of briquettes, it may be possible to reach profitability for all plant sizes and energy potential; however, this profitability is comparatively smaller to that obtained for large–scale pellet production.

TABLE 29.

Maximum acceptable feedstock prices – Briquettes replacing LPG

ENERGY POTENTIAL (MJ/kg)	MAX FEEDSTOCK PRICE (US$/tonne)			
	4 (kg/h)	40 (kg/h)	400 (kg/h)	4 000 (kg/h)
<13	$34	$18	$29	$32
<15	$42	$27	$37	$41
<17	$29	$29	$39	$43
<19	$62	$47	$57	$61

TABLE 30.

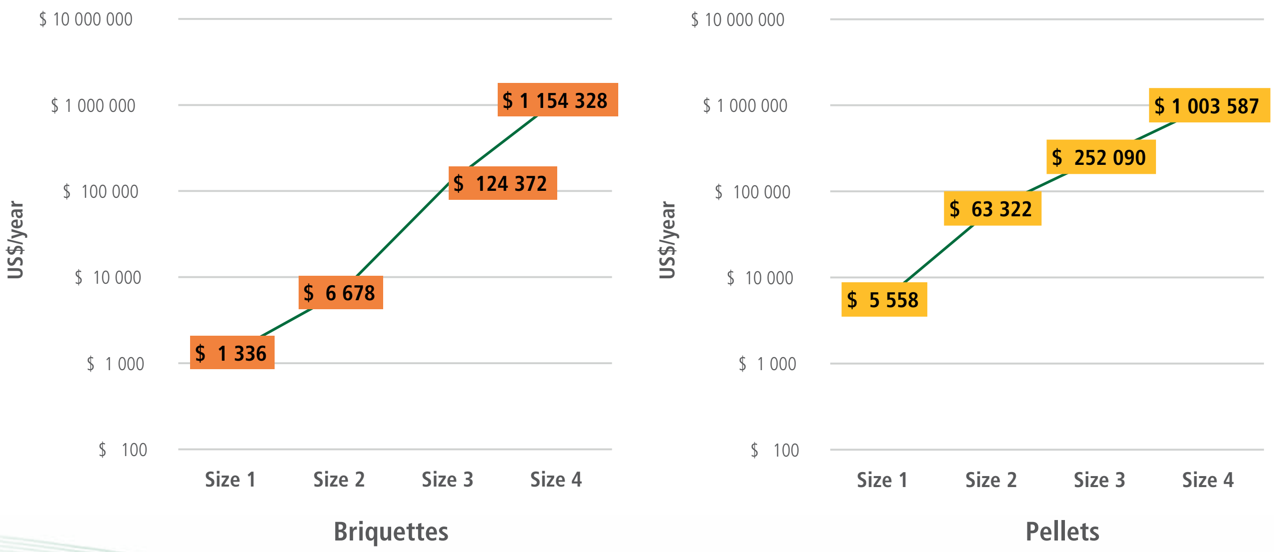
Maximum acceptable feedstock prices – Pellets replacing LPG

ENERGY POTENTIAL (MJ/kg)	MAX FEEDSTOCK PRICE (US$/tonne)			
	4 (kg/h)	40 (kg/h)	400 (kg/h)	4 000 (kg/h)
<13	$0	$0	$27	$51
<15	$0	$0	$39	$63
<17	$0	$0	$41	$67
<19	$0	$0	$68	$93

In summary, the results show that biomass–based briquettes and pellets could be promising options for LPG replacement. Overall, it can be stated that briquette technology is better suited to small–scale production, both manual (4 kg/h) and mechanized (40 kg/h). For large–scale mechanized production (400 and 4 000 kg/h), pellets would be a more profitable technology, as observed in the maximum feedstock prices in the pellets option, which allows for higher price flexibility. This can be explained by comparing the capital investments of briquettes and pellets (see Figure 73). The figure shows that overall investments for small–scale options are lower for briquettes than for pellets, with parity at larger scales. This also indicates that pellet technology is slightly more efficient than briquette technology (Haibo *et al.*, 2008). Pellet technology allows for more efficient biomass densification allows for more efficient biomass densification, with comparatively lower energy consumption, and consequently less operative costs. Thus, once investment parity is reached, pellet technology offers more competitive production conditions.

FIGURE 73.

Comparison of capital investments for briquette and pellet technologies



In general terms, it can be stated that the profitable production conditions for briquettes and pellets replacing LPG are low–cost feedstock, with high–energy potential, and that the planned production capacity should be small–scale for briquettes and large–scale for pellets. The feedstock that seem to be most promising are: citrus prunings, olive prunings, palm date prunings, cotton stalk, grape prunings, sugar cane bagasse, sunflower stalk, maize stalk and rice straw.

In the final level of analysis, the potential energy output was calculated from the set of feedstock identified and the availability determined in the natural resources assessment per governorate. In terms of energy output, as biofuels obtained through the physical transformation of biomass (unless they are pre–converted in charcoal), briquettes and pellets maintain the fuel properties of the initial biomass. As a result, the energy output will be more or less homogeneous from a burning point of view. In other words, the energy produced for the final consumer is the same whether briquettes or pellets are used, when they are based on the same residue. The major difference is found when comparing the energy output of different residues. Table 31 shows the potential energy from the initial biomass. The final transformation into useful energy will depend on the oven type selected, although overall modern briquette/pellet technologies reach 70–80 percent efficiencies (Clean Cooking Catalog, 2016).

TABLE 31.

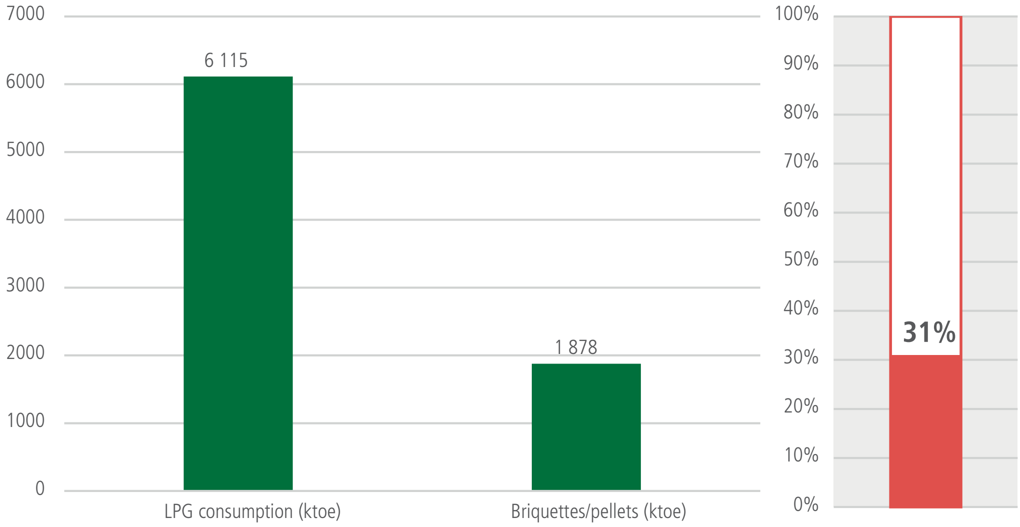
Total energy output in different governorates for briquettes/pellets

ENERGY OUTPUT (ktoe)										TOTAL ENERGY (ktoe)
GOVERNORATE NAME	CITRUS PRUNINGS	OLIVE PRUNINGS	PALM DATE PRUNINGS	COTTON STALK	SUGAR CANE BAGASSE	GRAPES PRUNINGS	SUNFLOWER STALK	MAIZE STALK	RICE STRAW	
Behera_ Noubaria	58.14	11.53	10.38	57.41	-	33.24	3.69	96.17	50.68	321.25
Sharkia	16.36	-	1.42	23.93	-	-	-	80.31	62.98	184.98
Dakahlia	1.23	-	-	25.40	-	2.02	-	25.21	109.65	163.51
Kafr_El Sheikh	1.20	-	2.55	54.35	-	-	-	23.55	74.16	155.82
Menia	1.33	-	-	-	35.92	7.63	-	85.71	-	130.59
Qena	-	-	-	-	109.75	-	-	18.55	-	128.30
Aswan	-	-	5.20	-	76.53	-	-	4.91	-	86.63
Menoufia	10.34	1.42	-	1.86	-	4.73	-	63.98	-	82.33
Gharbia	3.48	-	-	9.53	1.39	4.08	-	27.57	35.78	81.82
BeniSuef	1.72	-	-	3.52	-	1.96	-	67.21	-	74.41
Luxor	-	-	-	-	58.60	-	-	7.49	-	66.09
Fayoum	1.52	6.89	-	10.40	-	-	1.35	42.86	-	63.02
Suhag	-	-	-	-	14.94	-	-	46.67	-	61.61

	ENERGY OUTPUT (ktoe)									
GOVERNORATE NAME	**CITRUS PRUNINGS**	**OLIVE PRUNINGS**	**PALM DATE PRUNINGS**	**COTTON STALK**	**SUGAR CANE BAGASSE**	**GRAPES PRUNINGS**	**SUNFLOWER STALK**	**MAIZE STALK**	**RICE STRAW**	**TOTAL ENERGY (ktoe)**
Assuit	3.45	1.06	1.73	2.80	1.56	1.15	-	48.87	-	60.63
Giza	4.18	2.55	4.98	-	1.68	2.25	-	25.01	-	40.65
Qalyoubia	10.52	-	-	-	-	-	-	21.18	3.78	35.49
Ismailia	8.69	5.96	1.00	-	-	-	-	12.35	1.41	29.41
North Sinai	1.38	11.94	9.11	-	-	-	-	-	-	22.44
Damietta	-	-	-	3.75	-	-	-	1.12	17.15	22.02
Alexandria	-	-	-	3.38	-	-	-	14.31	-	17.69
New Valley	-	1.22	6.82	-	-	-	-	5.73	1.69	15.46
Matruh	-	10.21	3.19	-	-	1.47	-	-	-	14.87
Port Said	-	-	-	1.19	-	-	-	2.78	5.50	9.47
South Sinai	-	4.06	-	-	-	-	-	-	-	4.06
Cairo	-	2.80	-	-	-	-	-	-	-	2.80
Suez	1.11	-	-	-	-	-	-	1.07	-	2.19
Red sea	-	-	-	-	-	-	-	-	-	-

FIGURE 74.

Contribution to cooking target demand

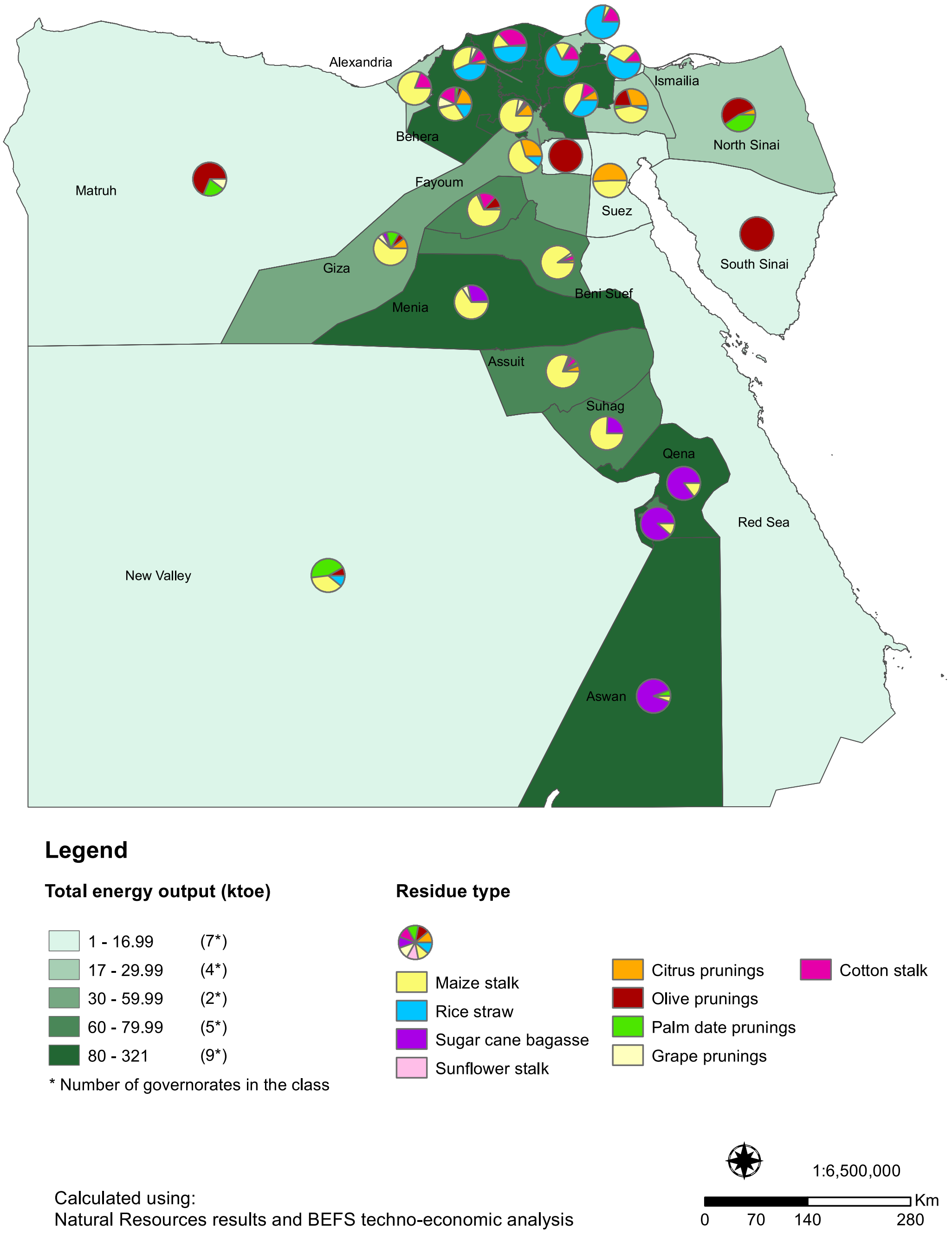


More than 75 percent of households in Egypt rely on cylinders filled with LPG for cooking and heating, since the majority of households are not connected to gas in their homes. The resulting energy output presented in Table 31 shows that it is possible to use the biomass residues available to achieve a combined potential energy output of 1 878 ktoe. Comparing this potential with LPG consumption figures reported by EIA (2010–2012) of

6 115 ktoe/year (EIA, 2015) reveals that there is a possibility to replace 31 percent of LPG consumption, supplying more than 1.6 million households and avoiding 3.6 million t CO_2eq/year. Like Figure 66, Figure 80 shows how overall, the highest capacity to generate bioenergy is located along the Nile river area, where the greatest number of people are settled.

FIGURE 75.

Total energy output–using briquette/pellet technologies



Calculated using:
Natural Resources results and BEFS techno-economic analysis

CONCLUSIONS

An evaluation was carried out to assess the viability of selected bioenergy technologies – direct combustion and biogas–based combined heat and power (CHP), as well as briquettes and pellets – based on the biomass assessment. The aim was to identify the potentially profitable and technically feasible combinations of energy production pathways, based on the identified biomass amounts available. In addition, the assessment quantified the extent to which these options could help to meet the renewable electricity targets set by Egypt and/or the potential use of biomass as an alternative to substitute LPG. In order to obtain a general sense of the potential of using biomass for electricity generation or for cooking, the total biomass calculated as available was first used to estimate the total maximum electricity potential. It was then used to estimate the total maximum amount of LPG that could be substituted. The final results of the assessment show which option could be most profitable for which location.

Cogeneration of heat and power

Biomass–based CHP production was assessed for its potential to generate electricity and was compared with the renewable electricity targets in Egypt. The economic viability and sustainability of a CHP plant depends on various factors, including levels of availability and access of residues, the technology used and the scale of production. Although all these variables were considered in this analysis, the most critical factor affecting the viability of CHP plants is the selling price of electricity.

Three scenarios were considered in terms of the selling price of electricity. The first price (Scenario 1) was 0.05 US$/kWh, representing the weighted average price of electricity for 2016–2017. The second price (Scenario 2) was 0.1 US$/kWh, which is the feed–in tariff price. The third comparison price (Scenario 3) was 0.15 US$/kWh, which considers a 50 percent premium, in addition to the current feed–in tariff price. The results of the assessment show that CHP schemes would start to be economically viable from a selling price of 0.10 US$/kWh.

Aside from the selling price, another element that can improve the economic viability of a bioenergy plant is minimizing the cost of residue. The results indicate that using a direct combustion scheme, the maximum payable price ranges from 41 to 61 US$/tonne under Scenario 2. Consequently, CHP plants should be developed close to, or attached to agro–processing facilities. This would allow the use of freely available feedstock and/or minimize collection and transport costs. Such a scheme would enable CHP plants to supply heat and electricity to the agro–processing plant. Any surplus electricity could then be sold to the central grid.

Under this set of profitable production conditions, the feedstock that met the technical requirements for direct combustion in CHP plants included maize stalk, rice straw, citrus prunings, olive prunings, palm date prunings, cotton stalk, grape prunings and sugar cane bagasse.

Due to the limited availability of manure identified in the biomass assessment component, biogas–based CHP plants that use manure only are not feasible at industrial level. However, biogas–based CHP plants that use a combination of manure and crop residues could be profitable, depending on the type of feedstock combination and its collection source. Among the feedstock options available, the most suitable combination emerged as a mix of cattle manure, sunflower stalk and sugar beet haulms. These types of biogas–based CHP plants would need to aim for stand–alone operation, given that they would require multiple biomass suppliers. In this case, the maximum feedstock price that these plants might accept ranges from 1.8 to 32.3 US$/tonne for production scales of 250 to 50 000 kWe. Therefore, locally designed supply chain models might be required to define the optimal locations of biogas to CHP plants and feedstock collection points. Additional analysis would be needed to identify potential consumers for the heat produced by these plants and to examine the alternatives of converting heat into additional electricity or cooling.

Assuming that all the available biomass were accessible, that logistics were in place and that all the biomass available were dedicated to electricity generation with CHP technologies, it would be possible to reach a maximum potential of 772 MW as the combined generation capacity of all the governorates. This potential could cover 7 percent of the 11 320 MW renewable energy target, supply more than 2.2 million households and avoid 2.9 million tonnes CO_2eq/year.

The governorates of Sharkia, Dakahlia, Behera, Kafr El Sheikh, Menia and Qena are the most promising areas, where it might be possible to establish the largest profitable plants. Higher generation capacities are generally found around the Nile River areas, where the country is more industrialized. The feedstocks with the greatest potential for energy generation in Egypt are rice straw in the north, maize stalk in the middle and sugar cane bagasse in the south, all through direct combustion.

Briquettes and pellets

The second energy end use alternative considered in this study was to use agricultural residues available to supplement some of the cooking energy demand in Egypt by replacing LPG. In terms of briquettes and pellets, profitability will depend on the market price that producers will receive. In this sense, there would be two possible comparison prices. The first is the current market price, which is 8.4 US$/GJ for briquettes and 7.6 US$/GJ for pellets. Briquettes and pellets are currently mostly used by high–end income households on barbeque fires, or sold to the export market. The second comparison price is the equivalent price of LPG (the subsidized LPG price), which is LPG 4.3 US$/GJ.
Results of the profitability assessment illustrate which briquette and pellet options may be feasible under current market conditions.

In the case of briquettes, the analysis shows that the maximum selling price can range from 18 to 62 US$/tonne. The variability in the selling price is a result of the spectrum of feedstock energy potential and the plant size. Conversely, pellets would reach maximum payable prices ranging from 27 to 93 US$/tonne. However, due to a higher initial investment than in the case of briquettes, only large–scale pellet production operations were found to be profitable. Overall, briquette technologies require lower capital investment, but are slightly less efficient than those for pellets. These latter require a greater initial investment, but due to their higher efficiencies, they are able to reduce operating costs and be more cost–effective at large–scale production.

The feedstock found to be most promising for briquette and pellet production were prunings from citrus fruits, including oranges, olives, palm dates and grapes, as well as cotton stalk, sugar cane bagasse, sunflower stalk, maize stalk and rice straw.

Based on these results, an effective approach for using agricultural residues for briquette and pellet production would require prioritizing briquette technologies at small–scale operation and those of pellets at large scale.

Again, assuming that all the available biomass were accessible, that logistics were in place and that all these crop residues were converted to briquettes/pellets, it would be possible to achieve a combined potential energy output of 1 878 ktoe/year. Comparing this potential to the LPG consumption figures reported by EIA (2010–2012) of 6 115 ktoe/year (EIA, 2016), it might be possible to replace 31 percent of LPG consumption with briquettes and pellets, supplying more than 1.6 million households and avoiding 3.6 million tonnes CO_2eq/year.

The governorates of **Sharkia, Dakahlia, Behera, Kafr El Sheikh, Menia** and **Qena** are the most promising areas for reaching the greatest substitution potential from briquettes and pellets.

CHAPTER 3

OVERALL CONCLUSIONS AND RECOMMENDATIONS

Overall, the analyses indicate that Egypt has the potential to produce sustainable bioenergy, especially from crop residues, which could help the country to satisfy its energy demand, as well as contributing to meeting its renewable energy and GHG emission reduction targets. Maize stalks, rice straw, sugar cane bagasse, cotton stalk, prunings and cattle manure can be used to produce sustainable bioenergy in Egypt. The Middle Delta region appears to be the most promising as far total availability of residues is concerned. At governorate level, Behera, Sharkia, Dakahlia and Kafr–El Sheikh are suitable locations for piloting a bioenergy project, due to their abundant availability of both crop and livestock residues.

Given the scope of this assessment, it should be noted that a number of assumptions on competing uses of agricultural and livestock residues, technical parameters and technology options were used in the study. Although these premises are reasonable, and were agreed upon with key national experts and stakeholders, further verification and validation of the results presented in the report would be crucial, since the quantity and quality of bioenergy in Egypt would depend on the quantity and stability of feedstock supply. Existing competing uses of crop and livestock residues can vary substantially across governorates, affecting availability as well as accessibility.

However, it is important to reiterate that the potential to produce bioenergy depends largely on the actual availability and accessibility of the residues and their geographical distribution. Therefore, the next step should involve validating the biomass availability and accessibility of residues in the most promising governorates identified in this assessment. In addition to this, there is a need for a long–term strategy – one that aims to ensure that the bioenergy produced from residues is economically viable as well as sustainable. This would entail establishing an agricultural residue value chain, ensuring a uniform and dependable supply of residues. All key stakeholders would need to be involved, and mechanisms to encourage information exchange between energy producers and biomass owners would need to be developed. Furthermore, policies would be required to encourage the proliferation of mechanization equipment for the collection and pre–treatment of residues, as well as facilities for post–harvest storage.

There are challenges in collecting and mobilizing residues for bioenergy generation. A key enabling factor could be to establish a biomass market and supply chain that would allow for an easy exchange of residues between biomass producers and bioenergy developers. Given the concentration of agricultural and other economic activities along Egypt's Nile River, it may be worthwhile examining opportunities for developing

logistical arrangements in and around the river, which could prove critical in the collection and mobilization of agricultural residues for bioenergy production.

The results of this assessment may be used by the country to create an integrated and efficient strategy for the smart use of biomass residues available for bioenergy production at national level, identifying specific bioenergy options that could be profitable, based on the biomass potential available within each specific region.

In general terms, results of this assessment show that using agricultural residues for energy production as electricity (CHP technologies), or as cooking fuel replacement (briquettes/pellets), can result in promising cost–effective options to increase energy access, reduce fossil fuel dependence and greenhouse gas emissions (GHG) and contribute to renewable energy targets. So far, the feedstock options considered have been the same for both CHP and briquettes and pellets. Therefore, the final decision on which combination to use at governorate level will depend on local availability and accessibility of residues, and the specific energy demand in each governorate.

The results obtained in this study show that producing sustainable and profitable bioenergy in Egypt is possible. One of the key messages that can be extracted from the techno–economic assessment is that profitability is related to a proper combination of the feedstock costs, energy potential and availability. These elements, coupled with an adequate technology selection, allow for profitable production. Thus, a feedstock that might emerge as too expensive to be used in CHP production would appear adequate for pellet production. Conversely, given the energy content of certain feedstock, these would be more efficiently used dedicating their full potential to electricity generation.

The overall results showed that the highest potential for energy production using biomass residues is located around the Nile River area. This is also the most densely populated part of the country, where higher energy supply is required. Given the high production rates of feedstock in this highly populated area, it is important to consider technologies that produce energy on a large–scale, such as CHP. Conversely, the desert and coastal areas are less populated and biomass availability is lower, so in these areas it is better to use small–scale energy production technologies.

After that, the following recommended stage would be to carry out a few selected pilot projects in the governorates where the highest potential has been identified. Five proposed options are listed below:

<u>CHP using rice straw:</u>

Rice straw in CHP plant attached to rice mills. In this way, the CHP plant would benefit from a continuous supply of rice straw and the rice mills could become a potential buyer for the heat and electricity produced. From a biomass point of view, the optimal location for this first trial could be in **Dakahlia** or **Kafr–El Sheikh** governorates. A more detailed verification of rice straw availability should be performed, considering other potential uses, such as animal feed.

CHP using maize stalk:

In the central part of the country, there is good availability of maize stalk residues, particularly in the **Menia** and **Sharkia** governorates. However, the high collection costs of this feedstock have a negative impact on profitability of CHP plants. It would therefore be necessary to conduct a field analysis in the specific governorates to help estimate the detailed collection costs and gain an understanding of the possibility of using this residue in CHP plants attached to maize mill industries.

CHP from sugar cane bagasse:

Energy production using sugar cane bagasse is a well–known technology applied in sugar mills. This feedstock is a very promising option, given its good availability and the absence of collection costs. A field analysis in the Upper Egypt region is needed to understand why sugar mill industries are not currently using this residue. Results of the assessment would provide a first indication that this option would be beneficial for sugar mills, allowing them to benefit from the energy potential of this residue type. The two potential governorates would be **Qena** and **Aswan**.

Biogas from cattle manure:

Cattle manure is still an attractive option for biogas–based CHP. Additionally, under codigestion, this residue can be used for biogas production together with crop residues that are available, but in smaller amounts. Using cattle manure would increase biogas generation capacities in the country. Locating CHP plants attached to food processing industries may not be the most cost–effective option, since residue collection may need to be conducted from multiple sources. As a result, the location of these plants would depend mostly on the biomass supply. Consequently, biogas to CHP producers would not necessarily have an industry outlet to which they could sell the heat produced. Alternatives for using the surplus heat produced would therefore need to be found in order to ensure economic viability. A field level analysis would be required to define the most cost–effective option to use this heat, either as cooling or for the generation of additional electricity, depending on specific local energy needs. Potential governorates would be **Behera, Menoufia** and **Beni Suef**.

Briquettes and pellets for cooking (to substitute LPG) from prunings:

Briquettes and pellets are the most flexible option, in that they can use different feedstock types and operate at various plant size levels. Given the size restrictions highlighted in the report, briquette and pellet production may represent an attractive option to promote cost–effective LPG replacement and create self–supply energy solutions. The most favorable governorate for an in–field small-scale briquette project could be **Behera, Ismailia** or **North Sinai**, using olive, citrus and palm date prunings.

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ANNEX

TABLE 32.

Number of cattle younger than 12 months – governorate level

GOVERNORATES	NUMBER OF CATTLE YOUNGER THAN 12 MONTHS			
	2011	2012	2013	AVERAGE 2011– 2013
Port Said	3 728	3 166	3 721	3 538
Ismailia	32 992	39 744	25 636	32 791
Suez	10 807	12 073	9 152	10 677
North Sinai	619	144	987	583
South Sinai	163	355	113	210
Alexandria	33 257	27 568	33 142	31 322
Matruh	2 015	2 166	408	1 530
Total Coastal region	83 581	85 216	73 159	80 652
Qalyoubia	92 091	112 373	83 503	95 989
Menoufia	172 425	176 025	178 433	175 628
Gharbia	159 102	168 516	152 694	160 104
Dakahlia	116 370	146 355	129 770	130 832
Kafr–El Sheikh	143 131	149 938	106 687	133 252
Behera	247 562	234 880	296 427	259 623
Sharkia	223 018	273 103	264 949	253 690
Damietta	41 944	48 037	24 302	38 094
Total Middle Delta region	1 195 643	1 309 227	123 6765	1 247 212
Cairo	1 985	7 301	3 982	4 423
Giza	79 989	89 184	84 684	84 619
BeniSuef	110 627	93 419	92 452	98 833
Fayoum	118 085	119 242	123 646	120 324
Menia	146 411	103 058	91 559	113 676
Total Middle Egypt region	457 097	412 204	396 323	421 875
Assuit	135 486	157 865	141 567	14 4973
Suhag	176 738	166 091	171 404	171 411
Qena	136 405	149 903	143 839	143 382
Luxor	42 898	41 305	67 758	50 654
Aswan	30 313	28 000	36 934	31 749
New Valley	37 438	29 367	28 272	31 692

GOVERNORATES	NUMBER OF CATTLE YOUNGER THAN 12 MONTHS			
	2011	2012	2013	AVERAGE 2011– 2013
Total Upper Egypt	559 278	572 531	589 774	573 861
Red Sea	357	390	157	301
Noubaria*	86 611	109 445	91 072	95 709
Total Newly Reclaimed Lands	86 968	109 835	91 229	96 011
TOTAL	2 382 567	2 489 013	2 387 250	2 419 610

Data source: ARC

*Noubaria is not an administrative governorate, but rather a specific zone within the Behera governorate. However, due to certain specifics, in terms of regions, this zone is presented separately as it is in official statistics.

TABLE 33.

Number of cattle between 12 and 24 months – governorate level

GOVERNORATES	NUMBER OF CATTLE BETWEEN 12 AND 24 MONTHS			
	2011	2012	2013	AVERAGE 2011– 2013
Port Said	4 165	7 278	2 607	4 683
Ismailia	30 515	32 870	29 727	31 037
Suez	11 593	13 102	10 991	11 895
North Sinai	601	150	972	574
South Sinai	152	517	103	257
Alexandria	36 752	37 997	36 032	36 927
Matruh	2 641	2 900	478	2 006
Total Coastal region	86 419	94 814	80 910	87 381
Qalyoubia	83 976	93 543	83 912	87 144
Menoufia	176 391	167 487	164 965	169 614
Gharbia	138 357	148 556	133 618	140 177
Dakahlia	117 904	127 592	116 246	120 581
Kafr–El Sheikh	142 232	154 999	91 222	129 484
Behera	235 194	220 610	282 372	246 059
Sharkia	213 977	239 911	224 765	226 218
Damietta	32 890	45 082	19 317	32 430
Total Middle Delta region	1 140 921	1 197 780	1 116 417	1 151 706
Cairo	16 357	16 460	3 457	12 091
Giza	85 623	96 674	108 951	97 083
BeniSuef	126 195	101 647	102 884	110 242
Fayoum	134 889	131 105	153 278	139 757
Menia	174 693	120 099	111 193	135 328
Total Middle Egypt region	537 757	465 985	479 763	494 502
Assuit	129 773	149 079	118 700	132517
Suhag	177 053	167 679	165 575	170 102
Qena	124 832	141 522	131 887	132 747

GOVERNORATES	NUMBER OF CATTLE BETWEEN 12 AND 24 MONTHS			
	2011	2012	2013	AVERAGE 2011– 2013
Luxor	43 386	42 985	61 727	49 366
Aswan	33 812	34 428	37 450	35 230
New Valley	34 088	26725	25 983	28 932
Total Upper Egypt region	54 2944	562 418	541 322	548 895
Red Sea	254	171	250	225
Noubaria*	83 996	98 339	99 738	94 024
Total Newly Reclaimed Lands	84 250	98 510	99 988	94 249
TOTAL	2 392 291	2 419 507	2 318 400	2 376 733

Data source: ARC

*Noubaria is not an administrative governorate, but rather a specific zone within theBehera governorate. However, due to certain specifics, in terms of regions, this zone is presented separately as it is in official statistics.

TABLE 34.

Number of cattle older than 24 months – governorate level

GOVERNORATES	NUMBER OF CATTLE OLDER THAN 24 MONTHS			
	2011	2012	2013	AVERAGE 2011– 2013
Port Said	6 804	5 388	5 559	5 917
Ismailia	51 267	63 162	40 523	51 651
Suez	20 305	25 440	22 594	22 780
North Sinai	1 056	352	1 587	998
South Sinai	677	1 165	802	881
Alexandria	60 877	59 219	55 611	58 569
Matruh	3 732	3 651	966	2 783
Total Coastal region	144 718	158 377	127 642	143 579
Qalyoubia	171 948	211 751	156 256	179 985
Menoufia	289 439	291 865	266 136	282 480
Gharbia	247 435	272 854	227 812	249 367
Dakahlia	187 883	227 163	242 367	219 138
Kafr–El Sheikh	228 834	232 985	204 468	222 096
Behera	393 174	398 248	492 924	428 115
Sharkia	397 221	438 772	403 345	413 113
Damietta	65 701	82 242	45 835	64 593
Total Middle Delta region	1 981 635	2 155 880	2 039 143	2 058 886
Cairo	4 260	12 999	8 903	8 721
Giza	157 293	167 747	149 494	158 178
BeniSuef	190 780	144 524	176 417	170 574
Fayoum	213 610	199 714	202 933	205 419
Menia	230 177	190 269	184 566	201 671

GOVERNORATES	NUMBER OF CATTLE OLDER THAN 24 MONTHS			
	2011	2012	2013	AVERAGE 2011– 2013
Total Middle Egypt region	796 120	715 253	722 313	744 562
Assuit	213 715	255 080	244 150	237 648
Suhag	282 568	277 802	257 057	272 476
Qena	211 965	252 732	202 405	222 367
Luxor	68 769	72 008	109 069	83 282
Aswan	52 999	61 387	61421	58 602
New Valley	61 988	49 339	36148	49 158
Total Upper Egypt region	892 004	968 348	910 250	923 534
Red Sea	656	645	225	509
Noubaria*	172 919	204 315	154 995	177 410
Total Newly Reclaimed Lands	173 575	204 960	155 220	177 918
TOTAL	3 988 052	4 202 818	3 954 568	4 048 479

Data source: ARC

*Noubaria is not an administrative governorate, but rather a specific zone within the Behera governorate. However, due to certain specifics, in terms of regions, this zone is presented separately as it is in official statistics.

TABLE 35.

Number of cattle per age class – governorate level (average 2011–2013)

GOVERNORATES	NUMBER OF CATTLE PER AGE CLASS (AVERAGE 2011–2013)			
	< 12 MONTHS	12 – 24 MONTHS	> 24 MONTHS	TOTAL
Port Said	3 538	4 683	5 917	14 139
Ismailia	32 791	31 037	51 651	115 479
Suez	10 677	11 895	22 780	45 352
North Sinai	583	574	998	2 156
South Sinai	210	257	881	1 349
Alexandria	31 322	36 927	58 569	126 818
Matruh	1 530	2 006	2 783	6 319
Total Coastal region	80 652	87 381	143 579	311 612
Qalyoubia	95 989	87 144	179 985	363 118
Menoufia	175 628	169 614	282 480	627 722
Gharbia	160 104	140 177	249 367	549 648
Dakahlia	130 832	120 581	219 138	470 550
Kafr–El Sheikh	133 252	129 484	222 096	484 832
Behera	259 623	246 059	428 115	933 797
Sharkia	253 690	226 218	413 113	893 020
Damietta	38 094	32 430	64 593	135 117
Total Middle Delta region	1 247 212	1 151 706	2 058 886	4 457 804
Cairo	4 423	12 091	8 721	25 235

GOVERNORATES	NUMBER OF CATTLE PER AGE CLASS (AVERAGE 2011–2013)			
	< 12 MONTHS	12 – 24 MONTHS	> 24 MONTHS	TOTAL
Giza	84 619	97 083	158 178	339 880
BeniSuef	98 833	110 242	170 574	379 648
Fayoum	120 324	139 757	205 419	465 501
Menia	113 676	135 328	201 671	450 675
Total Middle Egypt region	421 875	494 502	744 562	1 660 938
Assuit	144 973	132 517	237 648	515 138
Suhag	171 411	170 102	272 476	613 989
Qena	143 382	132 747	222 367	498 497
Luxor	50 654	49 366	83 282	183 302
Aswan	31 749	35 230	58 602	125 581
New Valley	31 692	28 932	49158	109 783
Total Upper Egypt region	573 861	548 895	923 534	2 046 290
Red Sea	301	225	509	1 035
Noubaria*	95 709	94 024	177 410	367 143
Total Newly Reclaimed Lands	96 011	94 249	177 918	368 178
TOTAL	2 419 610	2 376 733	4 048 479	8 844 822

*Noubaria is not an administrative governorate, but rather a specific zone within the Behera governorate. However, due to certain specifics, in terms of regions, this zone is presented separately as it is in official statistics.

TABLE 36.

Share of each governorate in the total number of cattle

GOVERNORATES	SHARE / PERCENT
Behera	14.7
Sharkia	10.1
Menoufia	7.1
Suhag	6.9
Gharbia	6.2
Assuit	5.8
Qena	5.6
Kafr–El Sheikh	5.5
Dakahlia	5.3
Fayoum	5.3
Menia	5.1
BeniSuef	4.3
Qalyoubia	4.1
Giza	3.8
Luxor	2.1
Damietta	1.5
Alexandria	1.4

GOVERNORATES	SHARE / PERCENT
Aswan	1.4
Ismailia	1.3
New Valley	1.2
Suez	0.5
Cairo	0.3
Port Said	0.2
Matruh	0.1
North Sinai	0.0
South Sinai	0.0
Red Sea	0.0

TABLE 37.

Number of cattle farms – governorate level (2011)

GOVERNORATES	NUMBER OF CATTLE FARMS			
	FARMS OF 10 TO LESS THAN 25 HEADS	FARMS OF 25 TO LESS THAN 50 HEADS	FARMS OF 50 HEADS OR MORE	TOTAL
Port Said	0	37	6	43
Ismailia	3	7	81	91
Suez	92	106	96	294
North Sinai	2	1	19	22
South Sinai	0	0	0	0
Alexandria	615	174	210	999
Matruh	0	0	3	3
Total Coastal region	712	325	415	1 452
Qalyoubia	47	36	310	393
Menoufia	27	20	88	135
Gharbia	254	197	170	621
Dakahlia	178	79	175	432
Kafr–El Sheikh	185	70	72	327
Behera	193	150	289	632
Sharkia	365	108	415	888
Damietta	0	23	115	138
Total Middle Delta region	1 249	683	1 634	3 566
Cairo	85	53	82	220
Giza	187	175	137	499
BeniSuef	9	123	121	253
Fayoum	467	618	366	1 451
Menia	11	102	163	276
Total Middle Egypt region	759	1 071	869	2 699
Assuit	100	214	83	397

GOVERNORATES	NUMBER OF CATTLE FARMS			
	FARMS OF 10 TO LESS THAN 25 HEADS	FARMS OF 25 TO LESS THAN 50 HEADS	FARMS OF 50 HEADS OR MORE	TOTAL
Suhag	16	321	264	601
Qena	0	0	10	10
Luxor	13	15	2	30
Aswan	19	45	38	102
New Valley	8	13	147	168
Total Upper Egypt region	156	608	544	1 308
Red Sea	13	29	9	51
Noubaria*	958	985	266	2209
Total Newly Reclaimed Lands	971	1 014	275	2 260
TOTAL	3 847	3 701	3 737	1 1285

*Noubaria is not an administrative governorate, but rather a specific zone within the Behera governorate. However, due to certain specifics, in terms of regions, this zone is presented separately as it is in official statistics.

TABLE 38.

Number of cattle farms – governorate level (2012)

GOVERNORATES	NUMBER OF CATTLE FARMS			
	FARMS OF 10 TO LESS THAN 25 HEADS	FARMS OF 25 TO LESS THAN 50 HEADS	FARMS OF 50 HEADS OR MORE	TOTAL
Port Said	0	36	7	43
Ismailia	11	5	83	99
Suez	93	103	96	292
North Sinai	14	8	17	39
South Sinai	0	0	0	0
Alexandria	616	196	211	1 023
Matruh	0	0	1	1
Total Coastal region	734	348	415	1 497
Qalyoubia	34	38	300	372
Menoufia	34	28	102	164
Gharbia	228	234	239	701
Dakahlia	159	89	165	413
Kafr–El Sheikh	162	117	93	372
Behera	466	221	327	1014
Sharkia	366	112	426	904
Damietta	7	19	117	143
Total Middle Delta region	1 456	858	1 769	4 083
Cairo	92	42	82	216
Giza	375	184	101	660

GOVERNORATES	NUMBER OF CATTLE FARMS			
	FARMS OF 10 TO LESS THAN 25 HEADS	FARMS OF 25 TO LESS THAN 50 HEADS	FARMS OF 50 HEADS OR MORE	TOTAL
BeniSuef	9	122	121	252
Fayoum	510	702	397	1609
Menia	24	84	144	252
Total Middle Egypt region	1 010	1 134	845	2 989
Assuit	144	238	81	463
Suhag	19	309	265	593
Qena	0	0	6	6
Luxor	19	16	2	37
Aswan	19	45	41	105
New Valley	5	12	155	172
Total Upper Egypt region	206	620	550	1 376
Red Sea	0	0	1	1
Noubaria*	962	983	283	2 228
Total Newly Reclaimed Lands	962	983	284	2 229
TOTAL	4 368	3 943	3 863	12 174

*Noubaria is not an administrative governorate, but rather a specific zone within the Behera governorate. However, due to certain specifics, in terms of regions, this zone is presented separately as it is in official statistics.

TABLE 39.

Number of cattle farms – governorate level (2013)

GOVERNORATES	NUMBER OF CATTLE FARMS			
	FARMS OF 10 TO LESS THAN 25 HEADS	FARMS OF 25 TO LESS THAN 50 HEADS	FARMS OF 50 HEADS OR MORE	TOTAL
Port Said	0	5	29	34
Ismailia	9	5	57	71
Suez	93	103	96	292
North Sinai	9	26	16	51
South Sinai	0	0	0	0
Alexandria	662	198	215	1 075
Matruh	0	0	2	2
Total Coastal region	773	337	415	1 525
Qalyoubia	34	156	328	518
Menoufia	32	37	108	177
Gharbia	291	202	208	701
Dakahlia	158	96	171	425
Kafr–El Sheikh	62	122	57	241
Behera	596	260	255	1 111

GOVERNORATES	NUMBER OF CATTLE FARMS			
	FARMS OF 10 TO LESS THAN 25 HEADS	FARMS OF 25 TO LESS THAN 50 HEADS	FARMS OF 50 HEADS OR MORE	TOTAL
Sharkia	425	123	473	1 021
Damietta	1 386	163	96	1 645
Total Middle Delta region	2 984	1 159	1 696	5 839
Cairo	92	53	82	227
Giza	452	127	97	676
BeniSuef	9	122	119	250
Fayoum	485	702	396	1 583
Menia	13	96	142	251
Total Middle Egypt region	1 051	1 100	836	2 987
Assuit	156	299	83	538
Suhag	27	339	252	618
Qena	0	0	7	7
Luxor	144	137	2	283
Aswan	142	86	85	313
New Valley	6	14	179	199
Total Upper Egypt region	475	875	608	1 958
Red Sea	0	0	2	2
Noubaria*	962	994	289	2 245
Total Newly Reclaimed Lands	962	994	291	2 247
TOTAL	6 245	4 465	3 846	14 556

*Noubaria is not an administrative governorate, but rather a specific zone within the Behera governorate. However, due to certain specifics, in terms of regions, this zone is presented separately as it is in official statistics.

TABLE 40.

Number of cattle farms – governorate level (average 2001 – 2013)

GOVERNORATES	NUMBER OF CATTLE FARMS (AVERAGE 2011–2013)			
	FARMS OF 10 TO LESS THAN 25 HEADS	FARMS OF 25 TO LESS THAN 50 HEADS	FARMS OF 50 HEADS OR MORE	TOTAL
Port Said	0	26	14	40
Ismailia	8	6	74	87
Suez	93	104	96	293
North Sinai	8	12	17	37
South Sinai	0	0	0	0
Alexandria	631	189	212	1 032
Matruh	0	0	2	2
Total Coastal region	740	337	415	1 491
Qalyoubia	38	77	313	428

GOVERNORATES	NUMBER OF CATTLE FARMS (AVERAGE 2011–2013)			
	FARMS OF 10 TO LESS THAN 25 HEADS	FARMS OF 25 TO LESS THAN 50 HEADS	FARMS OF 50 HEADS OR MORE	TOTAL
Menoufia	31	28	99	159
Gharbia	258	211	206	674
Dakahlia	165	88	170	423
Kafr–El Sheikh	136	103	74	313
Behera	418	210	290	919
Sharkia	385	114	438	938
Damietta	464	68	109	642
Total Middle Delta region	1 896	900	1 700	4 496
Cairo	90	49	82	221
Giza	338	162	112	612
BeniSuef	9	122	120	252
Fayoum	487	674	386	1548
Menia	16	94	150	260
Total Middle Egypt region	940	1 102	850	2 892
Assuit	133	250	82	466
Suhag	21	323	260	604
Qena	0	0	8	8
Luxor	59	56	2	117
Aswan	60	59	55	173
New Valley	6	13	160	180
Total Upper Egypt region	279	701	567	1 547
Red Sea	4	10	4	18
Noubaria*	961	987	279	2 227
Total Newly Reclaimed Lands	965	997	283	2 245
TOTAL	4 820	4 036	3 815	12 672

*Noubaria is not an administrative governorate, but rather a specific zone within the Behera governorate. However, due to certain specifics, in terms of regions, this zone is presented separately as it is in official statistics.

TABLE 41.

Number of layers – governorate level (poultry census 2008)

GOVERNORATES	LAYER BREEDER	LAYERS	BALADI LAYERS	TOTAL LAYERS
	000 heads/year			
Port Said	0	52	0	52
Ismailia	45	581	14	640
Suez	0	35	0	35
North Sinai	0	0	0	0
South Sinai	0	0	0	0
Alexandria	0	949	3	952
Matrouh	0	0	0	0
Total Coastal region	45	1 617	17	1 679
Qalubiya	0	2 197	986	3 183
Menoufia	40	952	0	992
Gharbia	0	1 742	178	1 920
Dakahlia	0	1 876	245	2 121
Kafr El Sheikh	6	268	9	283
Behaira	110	2 024	162	2 296
El Sharkeya	0	6 844	962	7 806
Damietta	0	308	0	308
Total Middle Delta region	156	16 211	2 542	18 909
Cairo*	135	5 113	0	5 248
Giza**	0	906	0	906
BeniSuef	0	169	0	169
Fayoum	0	202	132	334
Minya	0	615	0	615
Total Middle Egypt region	135	7 005	132	7 272
Assiut	6	119	16	141
Suhag	0	191	22	213
Qena	8	65	0	73
Luxor	0	0	0	0
Aswan	0	7	0	7
New Valley	0	0	2	2
Total Upper Egypt region	14	382	40	436
Red Sea	0	0	0	0
Total Newly Reclaimed Lands***	0	0	0	0
TOTAL	350	25 215	2 731	28 296

*Cairo includes the governorate Sixth October. ** Giza includes the governorate Helwan. ***Noubaria did not exist in 2008.

TABLE 42.

Number of layers – governorate level (poultry census 2012)*

GOVERNORATES	LAYER BREEDER	LAYERS	TOTAL LAYERS
		000 heads/year	
Port Said	0	50	50
Ismailia	217	311	528
Suez	0	32	32
North Sinai	0	59	59
South Sinai	0	5	5
Alexandria	0	1 031	1 031
Matrouh	0	12	12
Total Coastal region	217	1 500	1 717
Qalubiya	0	3 152	3 152
Menoufia	193	994	1 187
Gharbia	0	2 201	2 201
Dakahlia	0	2 134	2 134
Kafr El Sheikh	29	410	439
Behaira	531	2 804	3335
El Sharkeya	0	5 225	5 225
Damietta	0	621	621
Total Middle Delta region	753	17 541	18 294
Cairo	652	773	1 425
Giza	0	3 487	3 487
BeniSuef	0	14	14
Fayoum	0	243	243
Minya	0	65	65
Total Middle Egypt region	652	4 582	5 234
Assiut	29	185	214
Suhag	0	249	249
Qena	39	9	48
Luxor	0	0	0
Aswan	0	0	0
New Valley	0	0	0
Total Upper Egypt region	68	443	511
Red Sea	0	0	0
Total Newly Reclaimed Lands	0	0	0
TOTAL	1 690	24 066	25 756

*Data received included only the number of layers at the national level, so an assumption was made that the shares in 2008 for each governorate remained the same.

TABLE 43.

Number of layers – governorate level (average 2008 and 2012)

GOVERNORATES	2008	2012	AVERAGE
	000 heads/year		
Port Said	52	50	51
Ismailia	640	528	584
Suez	35	32	34
North Sinai	0	59	30
South Sinai	0	5	3
Alexandria	952	1 031	992
Matrouh	0	12	6
Total Coastal region	1 679	1 717	1 698
Qalubiya	3 183	3 152	3 168
Menoufia	992	1 187	1 090
Gharbia	1 920	2 201	2 061
Dakahlia	2 121	2 134	2 128
Kafr El Sheikh	283	439	361
Behaira	2 296	3 335	2 816
El Sharkeya	7 806	5 225	6 516
Damietta	308	621	465
Total Middle Delta region	18 909	18 294	18 602
Cairo	5 248	1 425	3 336
Giza	906	3 487	2 197
BeniSuef	169	14	92
Fayoum	334	243	289
Minya	615	65	340
Total Middle Egypt region	7 272	5 234	6 253
Assiut	141	214	177
Suhag	213	249	231
Qena	73	48	60
Luxor	0	0	0
Aswan	7	0	4
New Valley	2	0	1
Total Upper Egypt region	436	511	473
Red Sea	0	0	0
Total Newly Reclaimed Lands	0	0	0
TOTAL	28 296	25 756	27 026

TABLE 44.

Number of broilers – governorate level (poultry census 2008)

GOVERNORATES	BROILER BREEDER	BROILERS	BALADI BROILERS	TOTAL BROILERS
	000 heads/year			
Port Said	74	223		297
Ismailia	416	9 128		9 657
Suez	0	515		515
North Sinai	14	1 374		1 388
South Sinai	0	14		14
Alexandria	168	10 788		10 956
Matrouh	0	2 821		2 821
Total Coastal region	672	24 863		25 648
Qalubiya	43	35 961		49 948
Menoufia	30	14 730		14 760
Gharbia	85	41 052		50 766
Dakahlia	674	40 498		46 960
Kafr El Sheikh	19	16 109		17 337
Behaira	672	43 743		46 806
El Sharkeya	645	69 546		90 978
Damietta	124	9 205		11 973
Total Middle Delta region	2 292	270 844		329 528
Cairo*	395	18 080		19 732
Giza**	105	9 553		9 948
BeniSuef	0	7 074		7 074
Fayoum	6	8 583		11 158
Minya	99	16 868		16 967
Total Middle Egypt region	605	60 158		64 879
Assiut	0	9035		9 114
Suhag	29	1 924		2 236
Qena	24	673		966
Luxor	0	0		0
Aswan	0	0		0
New Valley	0	434		434
Total Upper Egypt region	53	12 066		12 750
Red Sea	0	158		158
Total Newly Reclaimed Lands***	0	158		158
TOTAL	3 622	368 089		432 963

*Cairo includes the governorate Sixth October. ** Giza includes the governorate Helwan. ***Noubaria did not exist in 2008.

TABLE 45.

Number of broilers – governorate level (poultry census 2012)

GOVERNORATES	BROILER BREEDER	BROILERS	BALADI BROILERS	TOTAL BROILERS
	000 heads/year			
Port Said	148	250		398
Ismailia	0	17 767		17 814
Suez	60	421		505
North Sinai	676	5 280		5 956
South Sinai	0	20		25
Alexandria	1 348	1 161		2 522
Matrouh	337	7 041		7 378
Total Coastal region	2 569	31 940		34 598
Qalubiya	211	32 926		51 127
Menoufia	116	12 909		13 025
Gharbia	86	60 877		72 785
Dakahlia	1 293	41 615		46 547
Kafr El Sheikh	1 352	25 297		26 860
Behaira	38	65 328		66 656
El Sharkeya	834	97 488		123 592
Damietta	249	14 764		17 728
Total Middle Delta region	4 179	351 204		418 320
Cairo	0	2 358		2 360
Giza	12	21 237		21 881
BeniSuef	0	6 817		6 817
Fayoum	199	24 543		30 099
Minya	58	189 667		189 725
Total Middle Egypt region	269	244 622		250 882
Assiut	48	13 392		13 525
Suhag	0	6 407		7 155
Qena	28	664		834
Luxor	0	1 823		1 823
Aswan	0	149		193
New Valley	0	921		996
Total Upper Egypt region	76	23 356		24 526
Red Sea	0	240	0	240
Noubaria*	170	35 656	354	36 180
Total Newly Reclaimed Lands	170	35 896		36 420
TOTAL	7 263	687 018		764 746

*Noubaria is not an administrative governorate, but rather a specific zone within the Behera governorate. However, due to certain specifics, in terms of regions, this zone is presented separately as it is in official statistics.

TABLE 46.

Number of broilers – governorate level (average 2008 and 2012)

GOVERNORATES	2008	2012	AVERAGE
	000 heads/year		
Port Said	297	398	348
Ismailia	9 657	17 814	13 736
Suez	515	505	510
North Sinai	1 388	5 956	3 672
South Sinai	14	25	20
Alexandria	10 956	2 522	6 739
Matrouh	2 821	7 378	5 099
Total Coastal region	25 648	34 598	30 123
Qalubiya	49 948	51 127	50 537
Menoufia	14 760	13 025	13 893
Gharbia	50 766	72 785	61 776
Dakahlia	46 960	46 547	46 754
Kafr El Sheikh	17 337	26 860	22 098
Behaira	46 806	102 837	74 821
El Sharkeya	90 978	123 592	107 285
Damietta	11 973	177 28	14 850
Total Middle Delta region	329 528	454 500	392 014
Cairo	19 732	2 360	11 046
Giza	9 948	21 881	15 915
BeniSuef	7 074	6 817	6 946
Fayoum	11 158	30 099	20 628
Minya	16 967	189 725	103 346
Total Middle Egypt region	64 879	250 882	157 880
Assiut	9 114	13 525	11 320
Suhag	2 236	7 155	4 696
Qena	966	834	900
Luxor	0	1823	912
Aswan	0	193	97
New Valley	434	996	715
Total Upper Egypt region	12 750	24 526	18 638
Red Sea	158	240	199
Total Newly Reclaimed Lands	158	240	199
TOTAL	432 963	764 746	598 855

TABLE 47.

Number of chickens per subcategory – governorate level (average 2008 and 2012)

GOVERNORATES	NUMBER OF CHICKENS (AVERAGE 2008 AND 2012)		
	LAYERS	BROILERS	TOTAL
	000 heads		
Port Said	51	348	399
Ismailia	584	13 736	14 320
Suez	34	510	544
North Sinai	30	3 672	3 701
South Sinai	3	20	22
Alexandria	992	6 739	7 730
Matrouh	6	5 099	5 105
Total Coastal region	1 700	30 124	31 821
Qalubiya	3 168	50 537	53 705
Menoufia	1 090	13 893	14 982
Gharbia	2 061	61 776	63 836
Dakahlia	2 128	46 754	48 881
Kafr El Sheikh	361	22 098	22 459
Behaira	2 816	74 821	77 637
El Sharkeya	6 516	107 285	113 801
Damietta	465	14 850	15 315
Total Middle Delta region	18 605	392 014	410 616
Cairo	3 336	11 046	14 382
Giza	2 197	15 915	18 111
BeniSuef	92	6 946	7 037
Fayoum	289	20 628	20 917
Minya	340	103 346	103 686
Total Middle Egypt region	6 254	157 881	164 133
Assiut	177	11 320	11 497
Sohag	231	4 696	4 927
Qena	60	900	960
Luxor	0	912	912
Aswan	4	97	100
New Valley	1	715	716
Total Middle Egypt region	473	18 640	19 112
Red Sea	0	199	199
Newly reclaimed lands*	0	199	199
TOTAL	27 026	598 855	625 881

Data source: Poultry census

*Noubaria was not presented as part of the Newly Reclaimed Lands in 2008, so the region includes only the Red Sea governorate (even on average).

TABLE 48.

Share of each governorate in the total number of chickens

GOVERNORATES	SHARE / PERCENT
El Sharkeya	18.2
Minya	16.6
Behaira	12.4
Gharbia	10.2
Qalubiya	8.6
Dakahlia	7.8
Kafr El Sheikh	3.6
Fayoum	3.3
Giza	2.9
Damietta	2.4
Menoufia	2.4
Cairo	2.3
Ismailia	2.3
Assiut	1.8
Alexandria	1.2
BeniSuef	1.1
Matrouh	0.8
Suhag	0.8
North Sinai	0.6
Qena	0.2
Luxor	0.1
New Valley	0.1
Suez	0.1
Port Said	0.1
Red Sea	0.0
Aswan	0.0
South Sinai	0.0

TABLE 49.

Share of each governorate in the total number of layers

GOVERNORATES	SHARE / PERCENT
ElSharkeya	24.1
Cairo	12.3
Qalubiya	11.7
Behaira	10.4
Giza	8.1
Dakahlia	7.9
Gharbia	7.6
Menoufia	4.0
Alexandria	3.7

GOVERNORATES	SHARE / PERCENT
Ismailia	2.2
Damietta	1.7
Kafr El Sheikh	1.3
Minya	1.3
Fayoum	1.1
Suhag	0.9
Assiut	0.7
BeniSuef	0.3
Qena	0.2
Port Said	0.2
Suez	0.1
North Sinai	0.1
Matrouh	0.0
Aswan	0.0
South Sinai	0.0
New Valley	0.0
Luxor	0.0
Red Sea	0.0

TABLE 50.

Share of each governorate in the total number of broilers

GOVERNORATES	SHARE / PERCENT
El Sharkeya	17.9
Minya	17.3
Behaira	12.5
Gharbia	10.3
Qalubiya	8.4
Dakahlia	7.8
Kafr El Sheikh	3.7
Fayoum	3.4
Giza	2.7
Damietta	2.5
Menoufia	2.3
Ismailia	2.3
Assiut	1.9
Cairo	1.8
BeniSuef	1.2
Alexandria	1.1
Matrouh	0.9
Suhag	0.8
North Sinai	0.6
Luxor	0.2

GOVERNORATES	SHARE / PERCENT
Qena	0.2
New Valley	0.1
Suez	0.1
Port Said	0.1
Red Sea	0.0
Aswan	0.0
South Sinai	0.0

TABLE 51.

Number of layer farms – governorate level

GOVERNORATES	NUMBER OF LAYER FARMS		
	2008	2012	AVERAGE
Port Said	2	2	2
Ismailia	44	46	45
Suez	3	4	3.5
North Sinai	2	16	9
South Sinai	3	3	3
Alexandria	99	89	94
Matrouh	0	1	0.5
Total Coastal region	153	161	157
Qalubiya	566	579	573
Menoufia	97	126	112
Gharbia	248	323	286
Dakahlia	103	277	190
Kafr El Sheikh	22	42	32
Behaira	104	110	107
El Sharkeya	759	1 145	952
Damietta	24	55	40
Total Middle Delta region	1 923	2 657	2 290
Cairo	143	15	79
Giza	30	48	39
BeniSuef	5	2	3.5
Fayoum	13	4	8.5
Minya	10	5	7.5
Total Middle Egypt region	201	74	138
Assiut	7	10	9
Sohag	5	5	5
Qena	5	2	4
Luxor	0	0	0
Aswan	0	0	0
New Valley	1	0	1
Total Middle Egypt region	18	17	18

GOVERNORATES	NUMBER OF LAYER FARMS		
	2008	2012	AVERAGE
Red Sea	0	0	0
Newly reclaimed lands*	0	0	0
TOTAL	2 295	2 909	2 602

Data source: Poultry census

*Noubaria was not presented as part of the Newly Reclaimed Lands in 2008, so the region includes only the Red Sea governorate (even on average).

TABLE 52.

Number of broiler farms – governorate level

GOVERNORATES	NUMBER OF BROILER FARMS		
	2008	2012	AVERAGE
Port Said	21	20	21
Ismailia	499	481	490
Suez	56	19	38
North Sinai	287	521	404
South Sinai	3	5	4
Alexandria	349	364	357
Matrouh	289	447	368
Total Coastal region	1 504	1 857	1 681
Qalubiya	2 471	2 882	2 677
Menoufia	779	727	753
Gharbia	2 532	3 906	3 219
Dakahlia	2 694	2 466	2 580
Kafr El Sheikh	986	2 191	1 589
Behaira	58 163	3 389	30 776
El Sharkeya	4 011	6 227	5 119
Damietta	396	680	538
Total Middle Delta region	72 032	22 468	47 250
Cairo	569	23	296
Giza	224	606	415
BeniSuef	359	477	418
Fayoum	673	1 366	1 020
Minya	989	1 568	1 279
Total Middle Egypt region	2 814	4 040	3 427
Assiut	923	1 272	1 098
Sohag	294	769	532
Qena	62	63	63
Luxor	0	73	37
Aswan	0	37	19
New Valley	50	44	47
Total Middle Egypt region	1 329	2 258	1 794

GOVERNORATES	NUMBER OF BROILER FARMS		
	2008	2012	AVERAGE
Red Sea	3	5	4
Newly reclaimed lands*	3	5	4
TOTAL	77 682	30 628	54 155

Data source: Poultry census

*Noubaria was not presented as part of the Newly Reclaimed Lands in 2008, so the region includes only the Red Sea governorate (even on average).

TABLE 53.

Number of chicken farms – governorate level (average 2008 and 2012)

GOVERNORATES	NUMBER OF CHICKEN FARMS		
	LAYER FARMS	BROILER FARMS	TOTAL
Port Said	2	21	23
Ismailia	45	490	535
Suez	3.5	38	41
North Sinai	9	404	413
South Sinai	3	4	7
Alexandria	94	357	451
Matrouh	0.5	368	369
Total Coastal region	157	1 681	1 838
Qalubiya	573	2 677	3 249
Menoufia	112	753	865
Gharbia	286	3 219	3 505
Dakahlia	190	2 580	2 770
Kafr El Sheikh	32	1 589	1 621
Behaira	107	30 776	30 883
El Sharkeya	952	5 119	6 071
Damietta	40	538	578
Total Middle Delta region	2 290	47 250	49 540
Cairo	79	296	375
Giza	39	415	454
BeniSuef	4	418	422
Fayoum	9	1 020	1 028
Minya	8	1 279	1 286
Total Middle Egypt region	138	3 427	3 565
Assiut	9	1 098	1 106
Sohag	5	532	537
Qena	4	63	66
Luxor	0	37	37
Aswan	0	19	19
New Valley	1	47	48
Total Middle Egypt region	18	1 794	1 811

GOVERNORATES	NUMBER OF CHICKEN FARMS		
	LAYER FARMS	BROILER FARMS	TOTAL
Red Sea	0	4	4
Newly reclaimed lands*	0	4	4
TOTAL	2 602	54 155	56 757

Data source: Poultry census

*Noubaria was not presented as part of the Newly Reclaimed Lands in 2008, so the region includes only the Red Sea governorate (even on average).


ENVIRONMENT – CLIMATE CHANGE – BIOENERGY – MONITORING AND ASSESSMENT
FAO - ENVIRONMENT AND NATURAL RESOURCES MANAGEMENT WORKING PAPER

Egypt's large agriculture sector generates a considerable amount of agricultural residues each year. Agriculture residues are currently used for animal feed or bedding or as soil fertilizers, among other uses. In addition, a considerable portion of these residues is disposed of by direct burning in the field causing serious threats to the environment. In some other cases residues remain unused.

In terms of energy and development, Egypt is making a push toward renewable energy and in general looking for more stable and reliable sources of energy considering some of the erratic supply over recent years. The country has set a goal for 20 percent of its electricity generation to come from renewable resources by 2020 – including hydro, wind and solar power.

Given the size of the agriculture sector and the need for energy diversification and stable supply, this report assesses the potential to generate some of the energy required by the country from the agriculture residues available. If the potential exists, energy generated from available agriculture residues could help put the country on a path toward more sustainable development, could help create jobs and market alternatives for agricultural products and improve people's livelihoods and access to energy, which is vital for inclusive economic growth.

Results of the assessment illustrate the amount of residues available in the country and for which type of energy production. The agriculture residues covered include crop residues, prunings and livestock manure. The energy end use options covered include combined heat and power facilities (direct combustion and biogas), briquettes and pellets. The analysis was carried out at the governorate level. The report quantifies which locations have most availability of biomass, which bioenergy options have more potential, and to what degree the renewable energy target could be met. In the conclusions, it is underscored how accessibility and mobilization of biomass remain one of the main hurdles to unlocking the full bioenergy potential estimated.

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