Appendices for: Pre-Feasibility Methodology to Compare Productive Uses of Energy Supplied by Stand-Alone Solar Photovoltaic Systems: A Tanzanian Case Study.

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## Appendix 1: Business Survey Data

**Barber**

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**Beauty Parlour**



**Irrigation System**

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**Food Drying**

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**Fishing Light**

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**Sewing/Tailors**

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**Agri-processing**

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**Bar/Café**

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**Office**

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**Technician Stall**

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**Phone Charging**

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**Egg Incubation**

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**Refrigeration – Dairy**

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**Refrigeration – Fish**

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## Appendix 2: Cost of PUE Equipment

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## Appendix 3: Services Per Person Per Month Calculation

**For some productive uses of energy, the calculation of services per month is not as simple as multiplying the cost of the service by the number of times a customer requires the service. For example, fishing lights would be a replacement for a kerosene lamp already used. This would have a reduction in kerosene cost and lamp filament replacement, but it does not directly relate to the amount of fish caught and hence income from the productive use. In this appendix these special cases are explained, and any calculations given.**

### Lighting for Egg Laying

|  |  |  |
| --- | --- | --- |
| **Item** | **Value** | **Source** |
| Number of hens per household: | < 50  | Less than 50 hens per household Assumption of 20 per business. |
| Number of hens under lamps: | 20 | Assuming 4 x 3W LED lights, each enough for 5 hens. Assumption.  |
| Approximate egg yield per hen at present: | 235 per year20 per month | (World Bank target level is 280 – 300) |
| Price of egg at market: | TZS 300 ($0.18)TZS 133 ($0.06) | TZS 4000 for tray 30 eggs to producer Fluctuate through year in response to demand including seasonal holidays. |
| Increase in egg yield: | 20-30% |  |
| Feed required per hen per day: | 120g per hen per day for layers. | Typical feed requirements 120g layers pellets per hen per day[[1]](#footnote-1)  |
| Cost of layer mash feed: | TZS 52,000 / 50kg$22.45 for 50kg$0.45 per kg | Price from 29/6/2020 [[2]](#footnote-2) |
| Percentage of rural households keeping chickens: | 85 % | Estimate |
| Number of employees at PUE: | 1 | Estimate |

**Calculations**

The number of eggs per month is calculated using the following:

$$Eggs\_{month}=N\_{hens}×Eggs\_{typical/month}×\left(1+Yield\_{increase}\right)$$

The profit per month will then be:

$$Income\_{month}=Eggs\_{month}×Cost\_{egg}$$

The cost of the business will be the PAYGo cost plus the cost of feed required. The cost of the feed is calculated here:

$$Cost\_{feed}= N\_{hens}×Feed\_{per hen per day}× Days\_{month}× Feed\_{cost per kg}$$

The monthly approximate profit can then be calculated:

$$Profit\_{month}=Income\_{month}- Cost\_{monthly repayment}- Cost\_{feed}$$

The off-grid population in Tanzania has been used in this analysis. Most rural households rear indigenous chickens [30], so the total number of potential egg laying units is estimated through the following calculation:

$$Total\_{egg laying business}=\left(^{Population\_{total}}/\_{N\_{household}}\right)×Percentage\_{keeping chickens}$$

### Egg incubation

|  |  |  |
| --- | --- | --- |
| **Item** | **Value** | **Source** |
| Operating hours: | 24 hours/day | Must be powered constantly. |
| Incubation days: | 23 | Typically 21 days – 23 used to include some cleaning days. |
| Hatchability Rate: | 70 % | Up to 90 % from manufactures information. |
| Flock size (100 eggs unit): | 10 hens 1 cock | Assumption – APL discussion with poultry farmer. 5 eggs per day, 150 eggs per month, 100 eggs per incubation batch. |
| Flock size (500 eggs): | 50 hens 5 cocks | Assumption – APL discussion with poultry farmer. 25 eggs per day, 750 eggs per month, 500 eggs per incubation batch. |
| Flock size (1000 eggs): | 100 hens 10 cocks | Assumption – APL discussion with poultry farmer. 50 eggs per day, 1500 eggs per month, 1000 eggs per incubation batch. |
| Eggs per hen per day: | 0.5 |  |
| Price of feed per month: | TZS 15,000$6.48 | Range from TZS 10,000 – 28,000No volume/weight given. This is average farmer cost.Field work (Date: March 2020). |
| Cost of layer mash feed: | TZS 52,000 / 50kg$22.45 for 50kg$0.45 per kg | Price from 29/6/2020 [[3]](#footnote-3) |
| Cost of chick mash feed: | TZS 55,000 / 50kg$23.75 for 50kg$0.475 per kg | Price from 29/6/2020 [[4]](#footnote-4) |
| Feed requirement per hen: | 150 g per day | Assumption – APL discussion with poultry farmer. Typical feed requirements 120g layers pellets per hen per day[[5]](#footnote-5) |
| Feed requirement per chick: | 25 g per day | Assumption |
| Inoculation cost per chick: | TZS 100 per chick$0.043 per chick | 2016 price |
| Sale Price: Broiler Chicks | TZS 3500$1.51 | Field work (Date: March 2020). |
| Average Mortality of Flock: | 20-25% |  |
| Number of employees at PUE: | 1 – 100 eggs1 – 500 eggs2 – 1000 eggs | Estimate |

**Calculations**

The number of chicks per month is calculated using the following:

$$N\_{chicks}=\left(N\_{hens}×Chicks\_{typical/day}×Days\_{month}× Hatchability\_{\%}\right)- Chick\_{mortality}$$

The profit per month will then be:

$$Income\_{month}=N\_{chicks}×Cost\_{chick}$$

The cost of the business will be the PAYGo cost plus the cost of feed required. The cost of the feed is calculated here:

$$Cost\_{feed hens+cocks}= N\_{hens +cocks }×Feed\_{per hen per day}× Days\_{month}× Feed\_{layer cost per kg}$$

$$Cost\_{feed chicks}= N\_{chicks}×Feed\_{per chick per day}× Days\_{month}× Feed\_{chick cost per kg}$$

$$Cost\_{innoculation}= N\_{chicks}×Cost\_{innoculation}$$

The monthly approximate profit can then be calculated:

$Profit\_{month}=Income\_{month}- Cost\_{monthly repayment}- Cost\_{feed chicks}- Cost\_{feed hens+cocks}- Cost\_{innoculation}$

The rural off-grid population has been used in this analysis. Most rural households rear indigenous chickens, so the total number of potential chick incubator units is estimated through the following calculation:

$$Total\_{chick incubation business}=\left(^{Population\_{total}}/\_{N\_{household}}\right)×Percentage\_{keeping chickens}$$

### **Fishing Lights**

|  |  |  |
| --- | --- | --- |
| **Item** | **Value** | **Source** |
| Appliance cost: Fishing Light | $ 50 FOB China$ 60 Landed in Tz | From APL costs.Including PV and battery system |
| Operating hours: | 8pm – 6am10 hours | 8 - 12 hours per night. Assumption & Field Work. Fishing is at night |
| Operating days per month: | 18 (4 days per week average) | 14 – 21 nights / month Never during full moon. |
| Cost of kerosene: | TZS 3200 ($ 1.40 ) / litreTZS 2120 ($ 0.95) / litre  | 2012 data.2020 data [[6]](#footnote-6)Small volume prices are 35 % higher than pump price  |
| Kerosene use: | 1.25 litre/ lamp /night | 1 – 2 litre / lamp / night |
| Kerosene Lamp repair costs: | $ 4 per month | Estimate |
| Number of lights per boat: | 6 | 4 – 10  |
| Number of crew per boat: | 6 | 4 – 8  |
| Number of Artisanal Fishermen – Tanzania: | 183,800 | 150,000 -2005 data.183,800 - 2016 data |
| Percentage of fisher within population in fishing zone: | 1.5 % | 2016 data |
| Number of employees at PUE: | N/A | Estimate |

**Calculations**

In these calculations a population map for the PUE has been created using the natural water feature data from a map of Tanzania. A 15 km buffer zone has been applied to the water features and it is approximated that people within that buffer will potentially be working on fishing-related economic activities. The population outside of that buffer is not included within this analysis. The total off-grid population within this buffer is 12,088,615. From 2016 data, within Tanzania there are:

* 183,800 fishers
* An estimated 4 million involved in the fishing sector
* Inland fisheries are exploited by 42,288 fishing vessels (mostly very small)
* 8,272 fishing vessels targeting Dagaa (inland)
* 7,664 fishing vessels targeting the coastal region.

Using the GIS analysis, around 30 % of people without a grid connection within the 15km buffer zone have incomes that are linked to the fishing sector, which seems reasonable. The percentage of fishers within the fishing population area is 1.5 %. The average number of fishers per vessel is 4.3.

The number of lanterns within an area comes from a calculation of the number of boats in an area:

$$Total\_{boats}=^{\left(Population\_{fishing area}×Percentage\_{fishers}\right)}/\_{Number\_{crew per boat}}$$

$$Total\_{lanterns}=Total\_{boats}×Number\_{lanterns per boat}$$

In this example the lights are a cost saving when compared to kerosene, rather than additional profit. So the cost of kerosene per lamp per month can be calculated from:

$$Cost\_{kerosene per month}=\left(Cost\_{ per litre}×N\_{litres per use}×N\_{days used}\right)+Cost\_{maintenance}$$

So, the ‘profit’ in this example is really savings from potential reduction in energy costs:

$$Savings\_{per lamp month}=Cost\_{kerosene per month}- Cost\_{monthly repayment}$$

$$Savings\_{per boat month}=Savings\_{per lamp month}×Number\_{lanterns per boat}$$

### **Refrigeration – Dairy**

|  |  |  |
| --- | --- | --- |
| **Item** | **Value** | **Source** |
| Dairy production: | 40 Litres/day7 days per week | For dairy example  |
| Dairy temperature: | 40 C | For dairy example |
| External temperature: | 30 C | For dairy example |
| Refrigeration temperature: | 10 C | For dairy example |
| Time to hold at temperature: | 10 hours | For dairy example |
| Typical spoilage rate: | 50 % | For dairy example |
| Assumed new spoilage rate: | 10 % | For dairy example |
| Supply price of milk: | TZS 1000 per litre$0.43 per litre  | TZS 200 – 1000 per litre2015 prices. TZS maximum used. |
| Percentage of households producing dairy, Tanzania: | 2 % | From total annual milk production and typical household production and size.Over 50 % of all working persons are in agricultural occupations. Around 40 % of households in Tanzania own livestock |
| Milk production annually, Tanzania: | 2,400 million litres | 2017/18 [[7]](#footnote-7)  |
| Number of employees at PUE: | 1 | Estimate |

**Calculations**

The dairy chilling example uses the following calculations:

The present loss due to spoilage is as follows:

$$Loss\_{present}=\left(\left(Production\_{l/day}×Spoilage\_{present}\right)×Days\_{month}\right)×Price\_{milk per l}$$

With a refrigeration system, this will be lowered to:

$$Loss\_{chilled}=\left(\left(Production\_{l/day}×Spoilage\_{chilled}\right)×Days\_{month}\right)×Price\_{milk per l}$$

The monthly profit can be estimated as:

$$Profit\_{month}=Loss\_{present}- Loss\_{chilled}- Cost\_{monthly repayment}$$

The maximum number of small dairy farmers is estimated here:

$$N\_{dairy farmers}=\left(^{Population\_{total}}/\_{N\_{ppl per hh}}\right)×Percentage\_{dairy farmer}$$

### **Refrigeration – Ice Making**

|  |  |  |
| --- | --- | --- |
| **Item** | **Value** | **Source** |
| Mass of ice block: | 5 kg each |  |
| Ice to produce per day: | 50 /day4 days per week, 17 days per month | Assumption – from discussion |
| Cost of ice block: | TZS 3000 per block$ 1.35 per block | Assumption – from discussion |
| Amount of fish chilled by block: | 8 kg |  |
| Population data: | Within 15 km of coast | Additional map layer created to only look at off-grid population  |
| Fish Catch Per Annum: | 450,000 tonnes | To calculate number of blocks of ice that may be required. |
| Percentage Catch needing Ice: | 30 % | Assume some sold direct, some dried, some chilled to market. |
| Number of Artisanal Fishermen – Tanzania: | 183,800 | 150,000 - 2005 data.183,800 - 2016 data |
| Percentage of fisher within population in fishing zone  | 1.5 % | 2016 data |
| Percentage of people working within fishing industry within population in fishing zone | 30 % | 2016 data |
| Number of employees at PUE: | 3 | Estimate |

**Calculations**

The profit per month can be calculated from the following:

$$Income\_{month}=Blocks\_{per day} ×Cost\_{block}×N\_{working days}$$

$$Profit\_{month}=Income\_{month}- Cost\_{monthly repayment}$$

The maximum number of ice-block businesses is calculated using the following:

$$Catch\_{per fisher annual}=^{Fish\_{per annum}}/\_{N\_{artisanal fishers}}$$

$$Ice Blocks\_{fisher per month}=\frac{Catch\_{per fisher annual}×Percentage\_{needing ice}}{\left(12×Fish\_{chilled per block}\right)}$$

$$Total\_{ice-block sellers}=\frac{Population\_{total}×Percentage\_{fishers}×Ice Blocks\_{fisher per month}}{\left(Blocks\_{per day}×N\_{working days}\right)}$$

### **Food Drying**

|  |  |  |
| --- | --- | --- |
| **Item** | **Value** | **Source** |
| Number of households serviced by one dryer:  | 40 | Estimate. The cost of equipment will be shared between these households. |
| Percentage using service: | 85% | Estimate. |
| Drying Capacity: | 20 kg |  |
| Crop type: | Mango | Example crop type for analysis. Assumes similar crop is available in most locations. |
| Crop production per hectare: | 17,000 kg per ha | 46,800 mangos per hectare, which is approximately 18 tonnes per hectare.17 tonnes per hectare |
| Typical farm size: | 2 ha |  |
| Size available for horticulture: | 0.25 ha | Assumption from discussion (see **Error! Reference source not found.** for more info). |
| Sale price of crop at market – High season: | TZS 100 – 300 per pcs$ 0.12 - 0.37 per kg | 2011 market price. Example crop type for analysis. Average mango weight 350g[[8]](#footnote-8) |
| Sale price of crop at market – Low season: | TZS 300 – 500 per pcs$ 0.37 – 0.62 per kg | 2011 market price. Example crop type for analysis. Average mango weight 350g[[9]](#footnote-9) |
| Spoilage rate (open Air): | 34 % | Field work (Date: March 2020).Africa: 30 % all crops spoiled, 50% for fruit and vegetables. |
| Time taken (open Air): | 48 hours | “12 hours - 2 days” from field work (Date: March 2020). |
| Spoilage rate (Controlled): | 10 % | Estimate |
| Time taken (Controlled): | 24 hours | Typically dries in ½ time of outdoor  |
| Number of employees at PUE: | N/A |  |

**Calculations**

The simple economic calculation for this PUE is to look at present crop yield and expected spoilage rate. This is then compared to any improvements using the drier. The difference between these two values, when converted into average monthly values, is the additional income from the PUE and must be greater than any costs associated.

$$Harvest\_{present}=Crop\_{per ha}×Size Farm\_{ha}×Spoilage\_{present}$$

$$Income\_{present}=Harvest\_{present}×Price\_{per kg high season}$$

$$Harvest\_{drier}=Crop\_{per ha}×Size Farm\_{ha}×Spoilage\_{drier}$$

$$Income\_{drier}=Harvest\_{present}×Price\_{per kg low season}$$

The cost of the system is shared between the households within the drier group, hence the potential increase in income per household, with a shared solar drier, is:

$$Profit\_{month}=\left(^{\left(Income\_{drier}- Income\_{present}\right)}/\_{12}\right)- \left(^{Cost\_{monthly repayment}}/\_{N\_{hh using dryer}}\right)$$

The maximum total number of solar dryer installations can also be calculated to gauge the size of the market in Tanzania.

$$Total\_{dryers}=^{\left(Population\_{total}×Percentage\_{use service}\right)}/\_{\left(N\_{ppl per hh}×N\_{hh using dryer}\right)}$$

### **Water Pumping Systems for Irrigation**

|  |
| --- |
| **Irrigation: 1 ha Cereal Crop System** |
| **Item** | **Value** | **Source** |
| Cost additional per m well depth: | $ 20 per m | Assumption: Additional cost per m well depth compared to minimum. |
| Training/ Agronomist cost: Monthly: | $ 40 | 2 days per month at $20 per day. |
| Liquid fertiliser cost: Monthly:  | $ 0 | Liquid not solid fertiliser is needed. Estimate. More information needed. |
| Increase in seed costs: Monthly: | $ 0 | No additional seed costs.Estimate. More information needed. |
| Additional costs: Total: | $ 40 | From above monthly costs |
| Area to irrigate: | 1 ha | Assumption – from discussion |
| Crop to irrigate: | Maize | Assumption – from discussion |
| Time spent collecting water: | 8.8 hrs/week | Situation at present.  |
| Maize yield (traditional rain-fed): | 1.4 tonnes/ha1.62 – 4.35 tonnes/ha3.0 tonnes/ha | 2016  |
| Sale price of Maize: | $ 20.00 / 100 kg $ 197.8 / tonne | $17 - $26 /100 kg: June 2019 data [[10]](#footnote-10)2016 FCO data [[11]](#footnote-11) (Average annual. Latest available) |
| Percentage of crop sold: | 50 % | Assume 50% is used locally |
| Percentage of population performing agriculture: | 82.6% |  |
| Water requirement per day: | 169 m3 / day | From Maize watering requirements and land area. Calculated above. |
| Irrigation months required: | May - Oct | Months of low precipitation.  |
| Depth of water: | Variable | Taken from water depth map – used in GIS analysis |
| Distance to field: | 383m |  |
| Number of employees at PUE: | 1 | Estimate |

|  |
| --- |
| **Irrigation: 0.25 ha vegetable crop drip-feed irrigation** |
| **Item** | **Value** | **Source** |
| Cost additional per m well depth: | $ 10 per m | Assumption: Additional cost per m well depth compared to minimum. |
| Training/ Agronomist cost: Monthly: | $40 | 2 days per month at $20 per day. |
| Liquid fertiliser cost: Monthly:  | $30 | Liquid not solid fertiliser is needed. Estimate. More information needed. |
| Increase in seed costs: Monthly: | $10 | Must be high-yield, rather than draught tolerant. Estimate. More information needed. |
| Additional costs: Total: | $80 | From above monthly costs |
| Area to irrigate: | 0.25 ha | Assumption – from discussion |
| Crop to irrigate: | Tomato | Assumption – from discussion |
| Time spent collecting water: | 8.8 hrs/week | Situation at present.  |
| Yield at present: | 5.85 tonne/ha34.0 tonne/ha | Situation at present. 2016  |
| Sale price of tomato: | $289.7 /tonne | 2016 FCO data[[12]](#footnote-12) (Average annual. Latest available) |
| Percentage of crop sold: | 50 % | Assume 50% is used locally |
| Percentage of population performing agriculture: | 82.6% |  |
| Water requirement per day: | 14 m3 / day | Calculated above. |
| Irrigation months required: | May - Oct | Months of low precipitation.  |
| Depth of water: | Variable | Taken from water depth map – used in GIS analysis |
| Distance to field: | 383m |  |
| Number of employees at PUE: | 1 | Estimate |

**Calculations**

The analysis for water pumping system must include the depth to ground water for the location, hence a geographical analysis must be used. For each different ground water depth location, the correct system size, and hence cost, must be used.

For each groundwater depth location, the depth is used to find the correct Homer analysis file and the irradiance data for the location is used to calculate the correct system size and cost for the location.

$$Cost\_{equipment}=Cost\_{pump}+Cost\_{Tank}$$

$$Cost\_{equipment total}=Cost\_{equipment}+\left(Cost\_{water depth factor}×\left(Depth\_{actual}- Depth\_{minimum}\right)\right)$$

The profit per month for an irrigation system has been calculated by assuming that a full additional harvest can be generated due to the improved irrigation. This is a ballpark estimate only and will have multiple factors which influence this calculation.

$$Income\_{annual}=Yield\_{kg per ha} ×Area\_{ha}×Percentage\_{sold}× Price\_{kg}$$

$$Income\_{month}=^{Income\_{annual}}/\_{12}$$

The estimated monthly profit can be calculated once the system repayment and any additional costs are considered.

$$Profit\_{month}=Income\_{month}- Cost\_{monthly repayment}- Cost\_{additional}$$

The maximum number of water pumping irrigation systems is calculated using the following:

$$Total\_{irrigation systems}=\left(\frac{Population\_{total}}{N\_{ppl per hh}}\right)×\%\_{using irrigation}$$

### **Cooking – Dagaa Fryer**

|  |  |  |
| --- | --- | --- |
| **Item** | **Value** | **Source** |
| Opening hours: Dagaa | 08:00 – 19:00 (fried after night fishing – 4 days per week) | Assumption & Field Work. |
| Average daily covers:  | 37 (dagaa) | Field Work in Tanzania, Feb 2020. |
| Average cost of meal:  | TZS 3000/ $1.30 per kg (dagaa) | Assumption – From discussionhttps://www.numbeo.com/cost-of-living/country\_result.jsp?country=Tanzania  |
| Firewood used per day: | TZS 28,000 / £12.10 (Dagaa Fryer) | Field Work in Tanzania, Feb 2020. |
| Population data: | Within 15km of in-land water bodies | Dagaa Frying: Additional map layer created to only look at off-grid population  |
| Dagaa Catch Per Annum: | 130,000 tonnes  | 42 % of inland fish catch (Inland Fisheries are 86 % or 85% of total catch) |
| Percentage Catch Fried: | 30 % | Dagaa Frying |
| Number of Artisanal Dagaa Fishermen – Tanzania: | 31,891 | 2015 data |
| Percentage of fishers within population in fishing zone  | 1.5 % | 2015 data |
| Number of employees at PUE: | 5 – Dagaa fryer | Estimate |

**Calculations**

Dagaa vendors are only servicing the fishing industry, so the population map is different. The population map has been created by looking at the population within 10 miles of any fresh-water body. This has been analysed using QGIS.

The profit per month for a Dagaa fryer can be calculated from the following:

$$Income\_{month}=Dagaa\_{per day} ×Cost\_{kg}×N\_{working days}$$

$$Profit\_{month}=Income\_{month}- Cost\_{monthly repayment}$$

The maximum number of Dagaa frying businesses is calculated using the following:

$$Dagaa\_{per fisher annual}=^{Dagaa\_{per annum}}/\_{N\_{dagaa fishers}}$$

$$Dagaa\_{fisher per month}=\frac{Dagaa\_{per fisher annual}×Percentage\_{fried}}{12}$$

$$Total\_{dagaa fryer}=\frac{Population\_{total}×Percentage\_{fishers}×Dagaa\_{fisher per month}}{\left(Dagaa\_{per day}×N\_{working days}\right)}$$

## Appendix 4: Load Profile Data

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1. <https://www.omlet.co.uk/guide/chickens/chicken_care/feeding/> [↑](#footnote-ref-1)
2. <http://tanfeeds.com/product/layers-mash/> [↑](#footnote-ref-2)
3. <http://tanfeeds.com/product/layers-mash/> [↑](#footnote-ref-3)
4. <http://tanfeeds.com/product/super-broiler-starter/> [↑](#footnote-ref-4)
5. <https://www.omlet.co.uk/guide/chickens/chicken_care/feeding/> [↑](#footnote-ref-5)
6. <https://www.globalpetrolprices.com/Tanzania/kerosene_prices/> [↑](#footnote-ref-6)
7. <https://allafrica.com/stories/201809100595.html> [↑](#footnote-ref-7)
8. <https://www.traditionaloven.com/foods/multi-units-converter/mangos-raw.html> [↑](#footnote-ref-8)
9. <https://www.traditionaloven.com/foods/multi-units-converter/mangos-raw.html> [↑](#footnote-ref-9)
10. <http://www.fao.org/giews/countrybrief/country.jsp?code=TZA> [↑](#footnote-ref-10)
11. <http://www.fao.org/faostat/en/#data/PP> [↑](#footnote-ref-11)
12. <http://www.fao.org/faostat/en/#data/PP> [↑](#footnote-ref-12)