UNITED NATIONS
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Adaptation and mitigation in the Kenyan tea industry

Country report

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

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From the People of Japan

Disclaimer

Content

- **Capital:**

Nairobi

- **Surface:**

582,646 km^2

- **Population:**

39.8 million

- **Biomass energy:**

78%

Background of the Tea Industry in Kenya

In 2014, exported foodstuffs represent USD2.59 billion, 52% of all exports and 4% of total Kenyan GDP. Tea exports made up 30% of the value of food-related exports, USD 787 million (Center for International Development at Harvard University, 2016; World Bank, 2016).

Uniquely in Kenya, about two-thirds of the tea is cultivated on smallholdings of 10-12ha (Groosman, 2011), although several large plantations organized under the Kenya Tea Growers' Association (KTGA) also supply a considerable amount. The KTGA is the largest single exporter of processed tea and the second largest exporter of black tea in the world (Blowfield & Dolan, 2010). Tea plantations usually supply Cut Tear Curl (CTC) factories (see Figure 2). The tea industry supports directly and indirectly an estimated 3 to 5 million people (Ethical Tea Partnership, 2011) making it major livelihood source for Kenya (Said-Allsopp & Tallontire, 2015).

Favourable tea growing regions in Kenya are those at fairly high-altitude with acidic, volcanic soils, well-distributed rainfall between the range of 1200mm to 1400mm per annum, sufficient sunshine hours and a mild climate (Figure 1). Tea production occurs all year round, but the highest yields coincide with the rainy seasons, March - June and then October - December. The ideal tea growing conditions in Kenya limit the need for agrochemicals to treat pests and disease.

Tea plantations in Kenya are situated in the highland areas of the Great Rift Valley, Mt. Kenya, the Aberdares, and the Nyambene Hills in the Central Kenya and the Mau escarpment, Kericho Highlands, Nandi and Kisii Highlands and the Cherangani Hills; with altitudes between 1500m and 2700m above the sea level. In 2007 it was estimated that 149 000ha was planted (Amde, Chan, Mihretu, & Tamiru, 2009). Factories are located near the place of production.

Recently, the tea industry has been confronted by high production costs, poor infrastructure, low levels of value addition and product diversification, inadequate research, development and extension, and declining global tea prices (Amde et al., 2009). These current obstacles are more exposed to the change of climate variability.

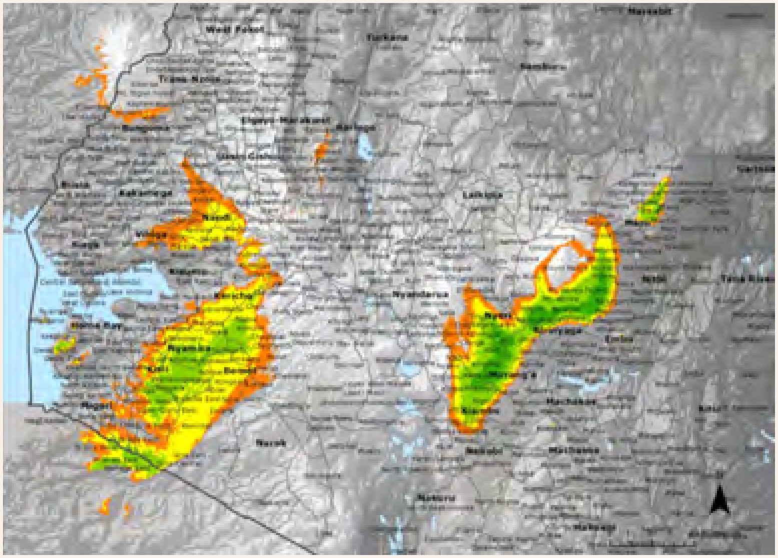
Figure 1. Current area of Kenya climatically suitable for tea production.

Current suitability

- Barely
- Marginal
- Good
- Very good
- Excellent

Scale

0 15 30 60 km



Source: Eitzinger, Läderach, Quiroga, Pantoja, & Gordon, 2011.

Comment: Only some is cultivated; the rest is occupied by other land-uses. Climate change will diminish tea production.

A Generic Value Chain of Cut, Tear, Curl (CTC) Tea in Kenya

Land Preparation, Planting, Plant Husbandry

Mulching and fertilizing are required during land preparation and tea growth to achieve and maintain adequately acidic soils and moisture. Tea plantations are perennial and healthy growth is maintained through the consistent application of various pruning techniques.

Plucking

Harvesting, or plucking, should take place at the correct maturity, i.e. an unfurled bud with two or three soft leaves. Although labor-intensive, manual harvesting is preferred as it enables more precise plucking; ensuring the highest quality harvest, supporting the health and productivity of the tea plants, and minimizing wasted leaf.

Transportation

Handling and care of fresh leaf after harvesting is important as careless or prolonged handling and transport increases post-harvest losses and/or decreases overall tea quality.

Withering

The leaves are left to wilt for 14-20 hours to begin the biochemical reaction for tea processing and reduce leaf moisture content to 71%.

Figure 2. Tea production chain

Cut, Tear, Curl (CTC)

The withered leaf is macerated with a rotor vane that crushes, tears, and mixes the leaf. This continues the enzyme activity inside the leaf, spreading the juices to the surface to stimulate oxidization, and forming dhool or the cut tea.

Fermentation

The dhool is passed into continuous fermenting units (CFUs) where leaf oxidization continues using cool humid air (22˚C-30˚C), for a duration of 110-150 minutes, allowing optimal fermentation.

Drying

Fluidized bed dryers rapidly reduce the moisture content of the leaf, terminating fermentation. Over a period of between 15-20 minutes, the fluidized bed dryers blow a stream of hot air (115-120˚C) on the tea particles until the leaf moisture content is reduced from between 67-69% to 2.8-3.2%. Drying too quickly can lead to bitter or harsh tea.

Sorting and Packaging, Distribution

The leaf is then cooled; mechanically sorted using a fiber extractor and sorting machine to clean, grade and winnow the tea; and finally packaged for storage or sale as black tea. Dispatch of packed teas is contracted to lorry transporters.

Stakeholders' Perceptions of the Impacts of Climate Hazards on Exposed Industry Processes

In 2015, as part of the vulnerability assessment, a vulnerability matrix (Figure 3) was compiled to capture the extent stakeholders that perceive various climate hazards to the impact of tea industry production processes. Representatives from tea stakeholders (farmers, public and private sectors) were involved. These stakeholders' perceptions of current and past climate vulnerability can offer insights and inform priorities for climate change adaptation(Stockholm Environment Institute, 2007).

The vulnerability matrix shows the *climate hazards* identified by stakeholders to threaten the tea industry (top row); each evaluated on a scale of 0-3. The rating depended on the perceived degree of impact the climate hazard would have on the components of the production process (first column). Being subject to climate hazards, the production process components are referred to as *exposure units*.

The scale was delineated as: 0 = no impact on the exposure unit, 1 = low impact on the exposure unit, 2 = medium impact on the exposure unit, 3 = significant impact[1] on the exposure unit.

The aggregated frequency of significant impact (Number of 3s) reveals stakeholders' perception of the impact of climate hazards on exposure units.

[1] 'Significant impact' was explicitly defined as 'impact the exposure unit has not coped with historically or is not able to cope with without an external support'.

Table 1. Vulnerability matrix

	Hail	Frost	Inadequate rainfall	Cold conditions	**Number of 3s**
Frequency	+	-		-	
Land preparation	2	1	3	0	**1**
Planting	2	2	3	1	**1**
Plant husbandry	3	2	3	3	**3**
Plucking	3	3	3	3	**4**
Transportation	1	1	0	1	**0**
Withering	1	2	2	3	**1**
Cut, Tear, & Curl	0	0	1	2	**0**
Fermentation	2	2	2	3	**1**
Drying	3	2	0	3	**2**
Sorting	0	0	0	0	**0**
Packaging	0	0	0	0	**0**
Distribution	1	0	0	0	**0**
Number of 3's	**3**	**1**	**4**	**5**	**12**

Stakeholders perceived a threat of significant impact on the following exposure units: plucking (4), plant husbandry (3), drying (2) and fermentation/ withering/ land preparation/ planting (1); although the probability and prevalence of the hazards occurring should also be considered to determine their adaptation priority.

Exposure units from the stage of land preparation through to the stage of drying were all thought to be at risk of medium impact from at least one of the climate hazards considered. Sorting, packaging and distribution, however, were perceived to be invulnerable to any climate hazards.

Stakeholders assessment of the impact

Plucking

Plant husbandry

Drying

Fermentation/withering/land preparation/planting

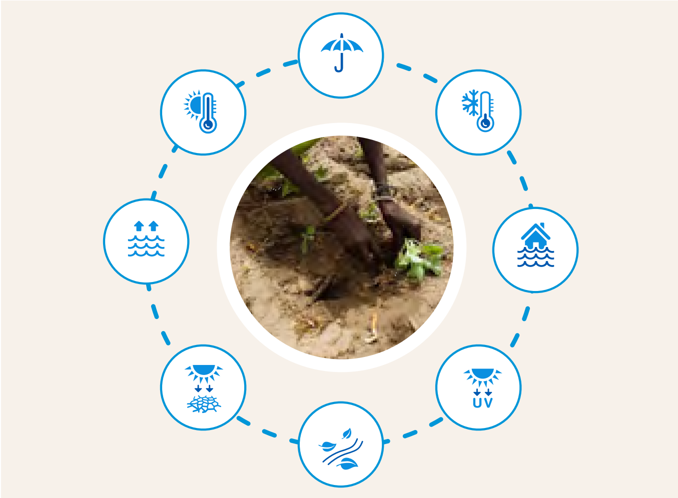
Projected Implications of Climate Hazards

Inadequate Rainfall

Inadequate rainfall for tea production is the consequence of drought and unpredictable rain patterns. As the climate changes, a small increase is actually expected in mean annual rainfall, increasing by approximately 2% by 2025 and 11% by 2075 (Bore, 2015). However, this increase will be outweighed by increases in temperature, the associated increases in evapotranspiration, and changes in rainfall distribution; so that on average there will be more periods and areas experiencing water deficit (Bore, 2015; Cracknell, 2015). More frequent episodes of drought (Ochieng, Kirimi, & Mathenge, 2016), prolonged dryspells between erratic and heavier rain events (Eitzinger et al., 2011) and higher humidity (Rosenzweig, Iglesias, Yang, Epstein, & Chivian, 2001) are all predicted by using various climate models.

1. Drought

Drought reduces the yield of tea shrubs as the low soil moisture content reduces photosynthesis, growth and survivability of plants (Cheserek, Elbehri, & Bore, 2015). The shallow roots of clonal tea shrubs are particularly susceptible to drought and erosion effects and exhibit severe stress during dry seasons (Ahmed, Orians, et al., 2014). Although leaf 'quality' can be retained during a drought (Ahmed, Stepp, et al., 2014); currently droughts incur average annual yield losses of between 12-20%, depending on the clonal stock and the length of the drought (Bore, 2015). Reduction in yield has run-on effects for the entire value-chain; supply disruptions upstream detrimentally affect



overall cost structures and sourcing options (Nyaoga, Wang, & Magutu, 2015). This results in broad financial losses and less income opportunity at farm-level (Bore, 2015; Chang & Brattlof, 2015).

2. Changes in Rainfall

Changes in the reliability and predictability of rainfall distribution and patterns can also have negative effects on tea yield and quality, especially combined with temperature increases (Ahmed, Orians, et al., 2014; Boehm et al., 2016; Bore, 2015; Cracknell, 2015; Elbehri et al., 2015). Changing patterns of rainfall and its distribution have already been seen to be problematic for tea production in Kenya (Cheserek, 2013; Cheserek et al., 2015) and the trends are projected to continue (Eitzinger et al., 2011). Although the volume of overall precipitation is increasing in Kenya, it is less evenly spread across the tea growing areas; dry periods are getting longer and more unseasonable; and floods, landslides and extreme rainfall events which increase can damage tea bushes and erode fertile topsoil (Eitzinger et al., 2011). Fluctuations in soil water availability also affect tea quality by impacting secondary metabolite concentrations (Ahmed, Orians, et al., 2014; Ahmed, Stepp, et al., 2014; Eitzinger et al., 2011; Schepp, 2009). Unpredictable rainfall complicates decisions along the value chain, from the timing of fertilizer application to the regulation of leaf moisture during processing.

3. Increased Humidity

Although humidity is not included in the matrix, this variable is also important. Increased humidity will have a negative impact at the withering and drying stages of tea production. When the air is moist during the rainy season, more energy is needed for these processes; whilst when it is dry, less energy is used. Also, under very wet or rainy conditions the leaves can arrive at the factory with higher than usual moisture contents (Hampton, 1992). Heavy rains can make roads impassable and delay the delivery of green leaves; the delays leading to a lesser-quality product and lags in production.

Hail

Hailstorms cause severe losses in some tea growing areas; hail would strip the tea shrubs of leaves. Furthermore, it not only destroys the current crop but also damages the bush stems. As a result, future crops would be reduced and plants are more susceptible to disease and pest problems. The effectiveness and speed of recovery from heavy hail damage can affect future crops for several years (Willson, 1992). Factories are closed after major events and many roles are suspended as the shrubs recover. In the western, tea producing counties of Kenya, i.e. Kericho, Bomet (Sotik) and Nandi; net loss of tea green leaf due to hail is generally estimated at over 2 million kilograms per year[2] (Bore, 2015). Kenyan tea producers are already facing more frequent hail episodes (Food and Agriculture Organization of the United Nations, 2012) and climate change scenarios project a considerable increase in future hailstorm damage (Botzen, Bouwer, & van den Bergh, 2010).

Cold Conditions

When temperatures are low, tea shrub growth is inhibited, ultimately leading to low yields and discouraging new planting. A minimum night temperature below 14°C leads to a reduction in the rate of growth, characterized by reduced shoot extension rates and low yields (Carr & Stephens, 1992; Cheserek et al., 2015). Cold conditions affect the fermentation, drying and Cut, Tear and Curl (CTC) processes detrimentally if they are not adjusted for (Hampton, 1992). Low temperatures also increase the energy requirements for the processes involved from withering through to drying, as more heating is used to ensure processes proceed optimally.

Frost

Although infrequent, radiation frost events incur widespread losses in Kenya. Furthermore, analysis of

[2] This only includes reported cases that are mainly from the large estates. Few of the small-scale tea producers in the area report hail losses.

long-term data suggests that these particular frost incidences are becoming more common in tea growing areas of Kenya (Bore, 2015; Cracknell, 2015; Food and Agriculture Organization of the United Nations, 2012). Radiation frost events occur in depressions and low lying areas where cold air can accumulate (Food and Agriculture Organization of the United Nations, 2016). These events are most likely to develop in the hilly areas of Nandi, Kericho, Bomet and Kisii. However, in early January 2012, a major frost event impacted all the tea growing areas across most of the tea producing counties in Kenya, destroying 20 million kg of green leaf (Gachenge, 2012)and causing an estimated 30% loss in yields (Bore, 2015). After a frost event, crops cannot be harvested for up to two and three months from the time the frost occurred (Bore, 2015). Suspension of tea production has social and economic implications, especially for farmers and factory workers (Chang & Brattlof, 2015).

Temperature Rise

The impact of increasing temperature was not considered in the matrix, potentially because warmer temperature can increase tea yields. However, a positive correlation exists between air temperatures and tea yields only when soil moisture is adequate (Cheserek, 2013). Furthermore, incidences of extreme temperature, either cold or hot, suppress tea yields: daytime maximum temperature in excess of 30˚C leads to a reduction in the rate and desired habit of growth for processing, and whilst heat can improve tea quality, heat extremes potentially damage leaves (Carr & Stephens, 1992; Cheserek et al., 2015).

The mean air temperature in East Africa is predicted to increase by about 2.5˚C by 2025 and 3.4˚C by 2075 (Bore, 2015), negating the small increase in rainfall over the same period and boding especially badly for tea production (Ochieng et al., 2016). Increased evapotranspiration from warmer temperatures could mean that the distribution of suitable tea growing land within the current tea-growing areas in Kenya will decrease (Bore, 2015; Eitzinger et al., 2011). The quality of tea grown at lower altitudes especially deteriorates in higher temperatures and humidity (Hampton, 1992). By 2050, areas under 2000 meters above sea level will be reduced in suitability. Significant areas west of the Rift Valley will reduce in their suitability for tea growth, with the most notable reduction in suitability being around Nandi County (Cracknell, 2015; Eitzinger et al., 2011).

Warmer temperatures, combined with increased humidity, will potentially proliferate new pests and diseases (Chang & Brattlof, 2015; Cheserek et al., 2015; Ethical Tea Partnership, 2011; Schepp, 2009) whilst destabilizing existing habitat and ecosystems unable to adapt (Cracknell, 2015). New pests and disease will incur additional costs and require new techniques to be appropriately managed.

During processing, extreme temperatures could interfere with withering where air temperature should not exceed 35˚C; higher temperatures reduce enzymatic action in the leaf (Senthil Kumar, Murugesan, Kottur, & Gyamfi, 2013). Excessive heat during fermentation can have an adverse effect on the balance of tea quality and flavour: theaflavins (responsible for tea ‘brightness’) can be catalyzed prematurely by heat, and deteriorate to suboptimal levels before the end of processing. Because of this, air temperature for fermentation should be maintained between 25˚C and 27˚C with 95% humidity (Senthil Kumar et al., 2013). Climate extremes could also affect tea if packaging has performance shortcomings. Although it is not identified in the vulnerability matrix to be impacted by climate change, numerous studies mention tea quality being deteriorated in storage by temperature and humidity (Obanda & Owuor, 1995; Preedy, 2012; Senthil Kumar et al., 2013).

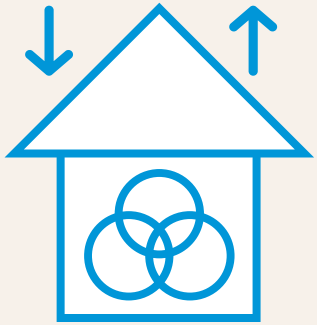
Adaptation Options for the Kenyan Tea Industry

Adaptation at Farm-Level

In recent years there have been numerous publications advising on potential climate change adaptation measures for the Kenyan tea production sector, focusing on adaptation interventions at farm-level (see: Cracknell, 2015; Ethical Tea Partnership, 2011; Schepp, 2009) as well as studies evaluating these interventions (Elbehri et al., 2015; Milder, Moroge, & Shames, 2015). These published manuals focus on plant husbandry. There is furthermore a strong evidence-base of the benefits, particularly, economic that farm-based interventions have for the entire tea value-chain (Blowfield & Dolan, 2010; The Sustainable Trade Initiative (IDH), 2013; van der Wal, 2008; Waarts, Ge, Ton, & Jansen, 2012), and multiple actors from public and private sectors, as well as community-based group along the value-chain can cooperate support and finance shifts to more sustainable practices (Kagira, Kimani, & Githii, 2012). However, it is recommended that a cost-benefit analysis be conducted before investing in an intervention (The Sustainable Trade Initiative (IDH), 2013; Waarts et al., 2012).

On-farm activities, Landscape Approaches

Soil and conservation management interventions are encouraged to maintain crop health and quality and minimise water and soil loss (Cracknell, 2015). These include conservation farming techniques, such as, cover crops and mulching, and double digging, and increasing organic matter and nutrient content of the soil by compost application, green manures and compost teas (methods especially suited to small-holders).The introduction of multipurpose shade trees can protect shrubs from scorching and improve soil (Bishaw et al., 2013).



To cope with uncertain rainfall distribution, water conservation and management options are also promoted, including water storage and harvesting, and including the introduction of cost-effective drip irrigation to improve soil water content and yields (Cheserek et al., 2015; Kigalu, Kimambo, Msite, & Gembe, 2008).

It is possible to manage frost by designing cold air drainage and diversion, and exploring suitable methods of crop protection, e.g. under-tree sprinklers (Food and Agriculture Organization of the United Nations, 2016). New tea clones are being bred to be more tolerant to frost, as well as droughts and pests.

Best practice plucking, conducted manually can also protect bushes from climate change pressures, contribute to pest and disease surveillance, and ensure the highest quality green leaf (Carr & Stephens, 1992).

Disaster Risk Reduction

Recovery strategies should also be in place to recover from natural disasters, such as, hail and frost events. These may also extend to taking insurance to minimize the devastation of disrupted production. Over the long-term, diversification of farmer household economies, particularly for farmers who only depend on small-scale tea production, is strategically important to strengthen the long-term resilience of farmers' businesses ((Nel) Wognum, Bremmers, Trienekens, van der Vorst, & Bloemhof, 2011).

Withering, CTC, Fermentation and Drying

A number of the factory processes crucial to ensuring tea quality are sensitive to temperature. Thus, measures are required to enable better temperature regulation at critical processing stages. Temperature regulation should account for factory microclimates created or exacerbated by external climate conditions and thermal or vapour emissions generated by other machinery and processing.

Withering and fermentation in particular require optimal temperatures to achieve desired tea character. This is to avoid any damage to leaves caused by overheating in hot conditions, suboptimal production from underheating in cool conditions or poor adjustments to fluctuations in humidity.

An example of a measure that could regulate fermentation is the integrated fermentation temperature and humidity automatic control system (F-THACS). Utilizing a process control system, heat exchanger, water and thermocouples, the F-THACS automatically increases and decreases temperature and humidity during fermentation. The result is that oxidation, fermentation and colour of the tea are optimized thereby achieving high quality tea.

The drying process could also be improved to better function in changeable and more extreme climate conditions. Introduction of automated fluidized bed dryers (FBDs) that use a process controller, pneumatic actuation steam valve and quick-response temperature sensor to control exhaust temperature in the last section of the dryer, will ensure more consistent moisture content in the tea, improving quality and reducing thermal energy diffusion. Incorporating heat recovery systems from flue gases and recirculation from dryer exhaust, would also assist in regulating the factory environment.

Such systems could adapt to climatic conditions and more reliably generate a higher quality product than the current manually adjusted tea dryers and fermentation machines equipped with only heat exchangers and water humidifiers. These current technologies are much more exposed to external variations in climate.

Packaging

It should be evaluated whether packaging materials maintain the quality of tea in storage when subject to extremes in climate conditions. Internationally, innovative research and development is being conducted in tea packaging materials that optimize the quality and nutritional properties of the tea (e.g. Zhao et al., 2012).

Long-Term Strategies

Long-term market diversification strategies would also be beneficial to consider at the processing level, to defend the industry against market fluctuations and leverage investments in more sophisticated technology and to play to the strengths of Kenya's quality product (Kagira et al., 2012). This is especially important with the changes in yields that will occur as viable land for plantations diminish. Kenya's tea exports mainly constitute of black CTC (crush, tear, curl) teas in bulk and exports of green teas are still very low (Export Promotion Council Kenya, n.d.), whilst consumer demand for green, 'value-added' and high grade teas is increasing, often at the expense of black tea (Groosman, 2011).


Carbon
CO2
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Mitigation Options for the Kenyan Tea Industry

Mitigation at Farm-Level

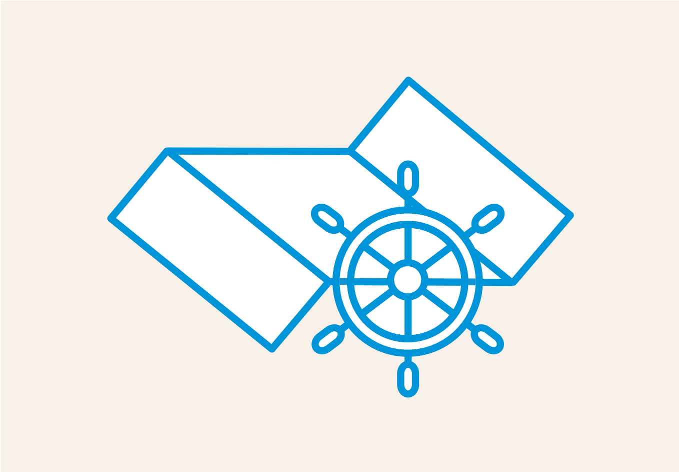
At farm level, climate change mitigation can often be achieved as a result of implementing appropriate climate change adaptation strategies (Milder et al., 2015). Furthermore, implementing many of the landscape approaches for adaptation suggested in the previous section; for example, soil conservation and management practices, or agroforestry practices, will result in fewer greenhouse gas emissions and also sequester carbon to an extent (Bishaw et al., 2013). Reducing the use of farm inputs, such as, fuel and fertilizer can also reduce the carbon footprint of the tea produced (Azapagic, Bore, Cheserek, Kamunya, & Elbehri, 2016).

Mitigation Options at Factory-Level

Climate change mitigation becomes increasingly important at the point of processing. Energy efficiency and low carbon energy sources are key to reducing emissions and can lead to cost savings as well as additional benefits, such as, lowered pollution levels.

More Energy-Efficient Technologies

Some of the heat recovery strategies mentioned in the adaptation section of this document, such as heat exchangers to recover heat from the furnace exhaust gas, heat pipes that recover heat from the dryer exhaust air and a circulation path for the dryer exhaust air, will also save energy in the primary drying



process in tea manufacturing. Energy efficiency can also be enhanced through automation of withering troughs, requiring switching fan motors to variable speed drives. Currently, the majority of factories use static beds for withering.

Minimize Waste

Wastage can be minimised by rethinking points where it frequently occurs, for example, redesigning truck cargo areas or replacing problematic dryers.

Optimize Use of Transport

More efficient use of lorries (i.e. at capacity) could avoid generating emissions through unnecessary transport. Furthermore, solar ropeways could be used to transport tea leaves in appropriate locations.

Tea Product Diversification

Other varieties of tea, such as, white, yellow and green tea, undergo a less emission intensive process, as the wilting and CTC process are not required.

Alternative Fuels

Tea producers should consider switching to alternative renewable energy sources, such as, solar and wind, although these technologies are still expensive and may not be affordable, particularly for small-scale producers. Solar air heating technology can be used for tea drying in place of inefficient fixed bed coal fired furnace and air heater. Biomass gasification derived producer gas has been quite successfully used for boilers in some tea growing regions (Dutta, 2015). Upcycled briquettes have been used quite successfully as an alternative fuel source in the Makomboki Tea Factory, which feeds its boilers with briquettes of macadamia, cashew and rice husks mixed with sawdust. The husks come from other factories, and the sawdust from mills that often have difficulty in getting rid of their waste (ICRAF, 2015). If the source is not carefully considered, however, using biomass resources can also have negative consequences. Relying on wood fuels for tea processing in Kenya has diverted fuel from households, cleared forests and remnant vegetation and led to the establishment of unsustainable quick-growing' plantations[3] (Azapagic et al., 2016).

[3] Some producers are growing water-thirsty eucalyptus trees along rivers and water streams, affecting water supply, particularly in lower rainfall years.

Conclusion: Some Opportunities and Challenges

Technology

Resource efficiency and cleaner technologies are fast emerging and need to be incorporated in the key processing areas. However, their uptake in the tea industries is generally low due to primarily low awareness levels and inhibiting costs, especially for small-holder farmers. Their uptake can result in low carbon and reduced climate change and vulnerability. Although some adoption is occurring, there is need for capacity building on climate change issues and funding support of the technologies by industries geared towards low carbon and climate resilient industrial development.

Financing

There is no specific funding mechanism for industries tailored for climate change initiatives. The management of operations are forced to mobilize funds for climate change mitigation and adaptation individually, a risk and disincentive to many. There is a need to allocate funding to support uptake of climate change mitigation and adaptation measures. Proactive approaches are required and private-public partnerships may provide opportunities; however, the development of tangible adaptation and mitigation plans is first required.

Information

Much research has been conducted into how the Kenyan tea sector can adapt to climate hazards, especially at the farm-level, compared with other industries in Kenya. However, there still seems to be a knowledge divide between academics and tea sector stakeholders. Climate change sensitisation needs to be continued. Currently, there is a lack of earnestness and commitment in regards to making the appropriate investments in low carbon and climate change resilient industrial development. Information related to climate change has been relegated to the periphery of the management decisions and policy actions. Adaptation and mitigation measures might be better communicated in terms of tailored cost-benefit outlooks and strategies for the value chains of individual operations. Disseminating and championing success stories of climate-innovators in the sector and practical 'climate-smart' interventions/extension amongst tea industry stakeholder communities, could also help galvanise action and improve awareness.

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This report examines the tea industry of Kenya, identifying the impacts of climate change on the tea value chain and suggesting options for climate change adaptation and mitigation.

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