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Climate Change Impacts on Apple Value Chain in Nepal

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***Abstract*: Climate change is significantly impacting Nepal's apple value chain, particularly in high-altitude regions like Jumla, Mustang, and Dolpa, where production, quality, and profitability are increasingly threatened. Rising temperatures, erratic rainfall, and pest outbreaks disrupt yields, requiring adaptation measures estimated at NPR 350,000 (US$ 2631) per hectare. This investment would fund high-density apple plantations (e.g., Fuji), pest management, irrigation, and orchard improvements, yet financial constraints limit smallholder farmers' access to these technologies. To address these challenges, a coordinated response is essential. Local governments, agricultural institutions, and cooperatives should provide subsidies or low-interest loans to enable farmers to adopt climate-resilient practices. Further investment in research and training is needed to develop pest-resistant varieties and adaptive cultivation methods. Infrastructure enhancements, including cold storage and transportation, are also critical to reducing post-harvest losses. Together, these strategies can improve the resilience and sustainability of Nepal's apple industry amidst climate challenges.**

***Keywords*: Climate Change, Apple, Value Chain, Nepal.**

1. Introduction

Climate Change (CC) in agricultural value chains (VCs) is primarily about risk, uncertainty and natural resources management to achieve sustainable and inclusive agriculture sector development and agri-food systems. The subject of CC in agriculture VCs transcends over several clauses of the Sustainable Development Goals (SDG) 2030, namely, SDG 2: Zero hunger; SDG 8: Decent work and economic growth; SDG 12: Responsible consumption and production; and SDG 13: Climate action (NPC 2018). Agricultural VC in Nepal is related with several national product accounts (e.g., agriculture and forestry, fisheries, industry, transport-storage and communications, wholesale and retail trading, finance and insurance) and multiple inter-disciplinary themes such as ecology, finance, foreign trade, environmental management, VC governance, science and technology, and so on.

Nepal ranks fourth in climate risk according to the Global Climate Risk Index, which analyzes to what extent countries and regions, have been affected by the overall impacts of weather-related events (Mandal & Giri, 2021; Nepal, 2019). According to the NPC (2020) the maximum temperature in Nepal has increased by an average of 0.056 degrees Celsius per year between 1971 and 2014, and this rate is even higher in the Himalayan region. The country is likely to continue experiencing some major impacts of CC due to its geologically and geographically sensitive topography. The Department of Hydrology and Meteorology (DHM, 2016) reports an increase in annual precipitation with aa average rate of 8.7 mm/year, and there is a major increase in monsoon rainfall (7.67 mm/year). In the high altitudes, precipitation has increased up to 6.6 mm/year, and decreased in mid-hills by -2.3 mm/year. Despite the increase in total rainfall, its patterns are increasingly changing across the country. Winter and pre-monsoon rainfalls are decreasing and unset, and the termination of the rainy season has gradually changed over time. There is an increase in the number of dry days in pre-and post-monsoon periods and of heavy rainstorms in many locations.

In this context, the objective of this study is to fulfil the knowledge gap by identifying climate impacts on apple VC and recommend appropriate adaptation measures that will influence investments in the VC. Through an assessment of climate impacts on different stages of the VC, the study contributes to long term sustainability of the VC, and builds the confidence of public and private investors with viable adaptation options to address the climate change risks. The specific objectives of the paper include the following:

1) Building CC scenario and micro-climate assessment;
2) Developing 'climate risk model' for apple VC;
3) Estimating potential climate impacts at different stages of the apple VC;
4) Identifying adaptation options to mitigate climate risks;
5) Socio-economic and financial analysis for choice of an adaptation option; and
6) Developing advocacy tool to influence public and private investment in the VC.

2. Methodology

The study methods refer to each of the six specific objectives explained in the previous chapter. First, the prioritization of the agri-VC is sorted out through the inception phase based on three steps, namely, literature review to build inventory of value-chains, application of Boston Matrix for business

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planning/attractiveness, and with stakeholders' considerations for emerging strategic and niche crops say, for example, apple etc. Selection of specific farm product and its basis would be dealt in a separate section as a distinct output. The study was conducted on February to March, 2022.

Second, this study used historical climate data (temperatures and precipitation) available for the last 30 years at the district level. The climate data was received from the Department of Hydrology and Meteorology (DHM). This data includes daily maximum, minimum, and average temperatures (^{0}C), and rainfall (mm/day). Spatial interpolation of seasonal precipitation and air temperature, and extreme events (length of dry spells, rainy days, per-monsoon, and monsoon drought) were estimated at a 1x1 km grid. The average temperature and precipitation of several Global Circulation Models (GCMs) were used for climate projections for Nepal.[1] A projected change in temperature and precipitation in Nepal is available at a 1x1 km grid. These model-forecasts are corroborated by ground-check through field surveys.

Third, regression models based on historical climate and crop production (yield) data were used to estimate the impact of climate variables in apple yields. Multivariate regression models were run using historical and cross-sectoral data (climate and crop production) combined for the major crop production areas/districts at the rate of about 9-10 districts per farm product say, for example, Jumla, Mustang and eight other districts for apple and so on depending on the products and its major distribution being chosen. Regression coefficient for maximum and minimum temperature, pre-monsoon rainfall, total rainfall, winter temperature, area under crop, and irrigation data were used to predict CC impact on current and future production. Table 2 presents the impact of climate and other variables on apple yields. The climate change impact assessment also includes literature review or the experts' judgments used depending on the data limitation. Partial market models, which involves, i.e., a consumer demand function, supply function and price mechanism for a commodity (say avocado), have been used to estimate the price elasticity of demand and supply for the final product of the VCs. Fourth, the climate effects at the farm production nodes spill over to other VC nodes, and climate change impact on other value chains (beyond farm production unit were derived from survey of value chain actors and value chain literature. Fifth, the CCA/M technologies identification and their costs are based on the VC actor/enablers' suggestions, literature review for technology and costs, and the researchers' best judgements. Sixth, for choice of options, the financial analysis [such as the benefit-cost ratio (BCR), internal rate of return (IRR), net present value (NPV) and payback period] is carried out for a project period of 15 years depending on the life of assets in question at two stages: i) Survey of VC actors' responses on the input-output relations in the VC business; and ii) Modification of the financial indicators based on the perceptions of the VC-actors or researchers' judgements or uses of parameters from the literature survey. Finally, the advisories are based on: i) Suggestions of VC-actors/enablers; ii) Findings of climate change impacts assessments, and commodity market models (elasticity of demand, elasticity of supply, market prices, and financial analysis; Note that the supply elasticity based on data on domestic production during 1990-2019 and real prices of the products (FAOStat), and the demand elasticity are based on data on the products' market arrival and process by months in wholesale market in Surkhet/ Kalimati, or retail shop iii) SWOT analysis; iv) Literature survey; v) Policy and institutional contexts; and vi) Some aspects of VC governance.

Field information was obtained using a questionnaire check list for the focused group discussion (FGD), key informant information (KII), experts' interviews, and related study reports. The survey activities covered 2 of the 77 districts in the country. Secondary data includes: Central Bureau of Statistics: National Accounts; Ministry of Agriculture and Livestock Development (MoALD) and related agencies: Statistical Information, Cost of Production Studies, Booklets on Commercial Farming of Apple; Department of Customs: Trade Statistics; and extensive review of the literature.

3. Results and Discussion

A. Value Chain Map of Apple Integrated to Climate Change

The VC maps presented below represent the three main components (i.e., VC ladder, VC governance, and CC management feedbacks) and are aligned with the explanations in the conceptual framework made. Short narratives for each VC nodes and CC impacts at those nodes for apple, are presented. The apple VC map is based on a survey in the Jumla-Surkhet-Dang corridor, and the Mustang-Pokhara corridor.

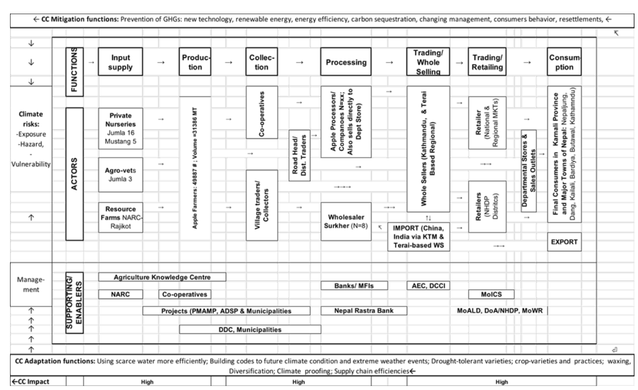

Fig. 1. Apple value chain map with respect to CC impact

Figure 1 shows that as per the stakeholders' perception and experts' views, the overall effects of CC on the apple VC relations are high. Details on various stages of value chain and CC impacts are presented below.

Nurseries and Planting Materials: There are 12–14 nurseries that produce apple grafted saplings and supply to farmers in Jumla, Karnali and beyond. The apple varieties cultivated in

[1] A general circulation model (GCM) is a type of climate model. GCMs and global climate models are used for weather forecasting, understanding the climate, and forecasting climate change. https://www.ipcc-data.org/guidelines/pages/gcm_guide.html

Key climate change impact on apple value chain	
1)	Drought effects on apple nurseries during winter and fungus infection (Apple scrub) during rainy season due to high and erratic rainfall.
2)	Aphid and Milly's bug insects heavy damage the apple plants due to low rainfall
3)	Increase soil acidity due to high-temperature ad CC impact and decrease yield and production.
4)	Orchard and plants drying due to low rainfall, decrease snowfall (during Feb-March), and increasing temperature in winter and summer seasons- yield decreased.
5)	Hailstones during late winter and early summer damage orchard and low yield (flowers and leaves damage).
6)	Transportation roadblocks at the time of marketing due to flood and landslide by heavy rainfall.
7)	Quality loss and storage damage in storage due to high humidity and temperature (5-10% weight lost within 1 month), and
8)	Heavy wind /storm damaged in the stage of flowering- especially in Mustang.

Jumla are traditional, and not certified for quality and diseases.[2] Horticulture Research Station in Rajikot, Jumla supplies healthy mother stocks. The district needs to import new varieties such as the Fuji/M and MM series. There is a lack of apple varieties for new climatic conditions.

Climate aspects: Productivity of local variety of apple is declining. The rise in temperature has resulted in an inadequate number of cold days required for local varieties of apple. Hence, the farmers are looking for new varieties. Apple Development Centre, Rajikot, Jumla is testing 21 varieties of the Apple. Their mother plants are ready, but these varieties remain to be released.[3] These varieties are: Canadian spur-type 10 varieties, and French spur-type 11 varieties. These varieties are better than the existing ones as they: i) Can compete with Fuji variety; ii) Start fruiting from the second year; iii) Yield about 62kg/plant; iii) Have low chilling period requirement; and iv) Are a late fruiting variety, and as a result, there would be no impact of black frosts (at flowering time from February to March).

Inputs and Agro-vets: Agro vets sell fertilizers, bordo mixture, pesticides and insecticides, and agriculture tools and equipment such as secateurs, pruning saw, sprayers, apple harvesting poles, plastic crates, harvesting bags, and aluminium stairs to apple produces. They undertake wholesale (dealer) and retail business in coordination with input suppliers. Most of them provide information to apple farmers on management practices. While Jumla is declared organic agriculture district, there is a lack of organic technology and inputs for apple cultivation. The soil acidity is high reportedly due to increase in temperature and CC impact resulting in decreased yield and production in recent years.[4]

From the water and other natural resources management point of view, the major issues in apple cultivation are: i) Lack of irrigation calling for water resources conservation, rainwater harvesting, irrigation systems, and snow harvesting; ii) Lack of compost manures because the farm/forest lands do not have much grasses to feed the animals, which are the source of farm yard manures (FYM); iii) Lack of herbal or bio-pesticides even though there are high incidences of diseases (leaf dropping, fruit pinnacle weakening/rotting, insect (mealy-bug) growing in the past; and iv) Lack of electrification for fam power and energy.

Farm Production and Farmers: Apple contributes about 20% to the household income of the population surveyed. Its production can be increased by 20% if the farm production conditions are set right.[5] Farmers grow apple varieties like Red Delicious and Jonathan because the fruits remain in the tree/do not fall even if it is late to pluck the fruit, and can tolerate some dryness and rise in temperature. All the farmers have knowledge of CC impacts such as increase in warm days and decrease in colder days; decrease in average rain fall and snow fall, and increase in dryness; high wind velocity destroying crops; diminishing of indigenous crop species; increase in new diseases and pests. They also have knowledge of climatic factors such as black frost, hailstorms, limited chilling days, dryness, lack of snow fall, and non-climatic factors such as lack of pollinators plants are hampering apple production. Aphid and Milly's bug insects heavily damage the apple plants due to low rainfall. Orchard and plants dry out due to low rainfall, decreased snowfall (during Feb–March) and increasing temperature in winter and summer seasons, resulting in low yield. Hailstones during late winter and early summer damage orchard, resulting in low yield (flowers and leaves damage). Heavy wind/storm caused damage in the stage of flowering, especially in Mustang.

The farmers intend to introduce new practices in farming as follows: i) Use of motor pump as irrigation is lacking; ii) Use of pipe instead of open canal (for canal alignment stability, and economy of water); iii) Beginning of tree training and pruning to decrease insect-pest occurrence; iv) Use of irrigation/water lift-pumps more frequently in the dry season; and v) Improvement in apple orchard management (pruning, soil moisture and nutrients, hedging, plant protection and so on) to improve the quality of apples.

Storage and Transport, and Farmers' Groups/Cooperatives, IMPEX-Traders and Wholesalers and Retailers: Apple storage takes places at three stages as part of post-harvest handling, agricultural marketing and wholesale trade. The efficiency of cellar stores remains to be ascertained, but these are underused. About 14% apples are of grade-D types. There were instances of DADO supporting a grading machine of 'vibrating type' to a cooperative. However, this machine was not used and was reported that it would damage the apple-fruit's skin.[6] The losses in wholesale trade are about 5% mainly because of rise in temperature of apple containers during long hours of transportations. Further, the storability of Jumla apples is quite low, partly because the farmers harvest apple pre-maturely in order to avoid competition with the arrival of apples from China

[2] Based on discussion with the PMAMP officials, Jumla.

[3] Discussions with Mr. Raj Kumar Giri, Acting Chief of the Rajikot Farm, and Lal Bahadur Raut, LRP and nursery owner in Jumla, and Mr Rajan Sherpa in Tukuche, Mustang.

[4] Based on discussions with the LRP (local resource person).

[5] Based on discussions with Kali Daha Vegetable and Fruit Farming Group, PMAMP and local traders in Jumla, and Syalom Multipurpose Agriculture Cooperative in Mustang.

[6] Based on discussion with President of District Cooperative Federation, Jumla.

Table 1
Adaptation options for climatic risks in apple value chain

VC Node	Climate Risks Adaptation Options
Input supply	Improved variety to adapt CC, insect and diseases
Production	Replacement with improved sapling
	Water conservation
	Mulching and irrigation
	Timely control of insect and disease (training)
Collection, grading, packaging	Avoid freezing and chilling temperature
Wholesale	Avoid high temperature with precooling under the shade
	Waxing
Retail	Avoid high temperature with precooling under the shade

in major consumption hubs. During storage, the damage ratio is about 4.44%.[7] Damage to apples during storage and transport is very high. Quality loss and damage in storage is due to high humidity and temperature (5–10% weight lost within a month). The stakeholders' suggestions to improve the storage of apples from the CC angles include: i) Relocation of cellar stores near production pockets and possibly uses of solar PV panels; ii) Improvement in the road and transport to minimize the effects of floods, landslides and bad roads to reduce time in transport and improve safe handling of fruits during transport; iii) Improvement in cold chains; iv) Supply of standards machines for grading of apples; iv) Introduction of varieties of apples that have better shelf life; v) Air-conditioned rooms for storage of apples; and vi) Improvement in the electricity supply systems' power outages and voltage stability for smooth function of the air conditioning systems.

Agro-Industry and Apple-Based Products, and Processing Business: Industries use apple (especially Grade-D types) as raw material to produce dried apples, apple cider, juice, wine and brandy.[8] Jumla has three apple processing firms but they are struggling for continued operation due to a lack of raw materials, infrastructure, market demand, modern technology, skilled manpower, appropriate woods for aging of wine, decline in production of local variety of apples, and shortage of investment funds. In addition, apple-based agro-industry is affected by CC through the shortage of low-cost renewable energy, clean water, raw materials, and sturdy infrastructure to link the factory to the apple production pockets and the market. In addition, they burn fuel woods to produce steams for drying.

Consumers: It is unclear whether consumers prefer organic Jumla or Mustang apples over the foreign ones. Nepali apples are available only for a limited number of months in a year. The methods to sell apples by retailers to the consumers vary from with or without brands, with or without certification of quality, and from street hawkers to departmental stores.[9] Losses in the value of apples during retail operations and its relations with CC remain to be ascertained.

Support Service, and Enablers and Facilitators:

1) Federal Ministry of Agriculture and Livestock Development (MoALD) and its National Fruit Development Centre facilitate research, demonstration, infrastructure support, and production. Exclusion by PMAMP of the small-scale apple producers to emphasize deals with large-scale companies has bypassed a large number of producers.
2) Provincial Ministry of Agriculture Development and its Directorate facilitate the block and pocket program development, infrastructure support, production and business through policy lobbying and policy formulation and program budgetary support. Since the government decided to promote Jumla as organic agriculture district, it ought to expedite the development of organic technology.
3) Agriculture Knowledge Centres (AKC) and municipalities provide apple saplings and other inputs under subsidy programs, provide technical services to farmers, facilitate groups/cooperatives in developing proposal on schemes and regulate those programs, and support in building cellar stores at cluster level owned by group/co-operative.
4) AKCs, Plant Quarantine and Pesticides Management Centre, Centre of Agriculture Infrastructure Development and Agricultural Mechanization Promotion/DoA facilitate in trading activities by providing technology and establishing collection centre and related market structures, and offering export-related support.
5) Prime Minister Agriculture Modernization Program (PMAMP) helps establish cellar stores, collection of apples, establishing apple orchards, import of high-density variety saplings through Agro-Manang Pvt Ltd to establish modern apple farms. PMAMP has developed super zone (=>1,000ha) program in Jumla. High Value Agriculture Commodities (HVAC) Project/Agriculture Sector Development Programme (ASDP) support in apple production, particularly by small farmers.
6) NARC Horticulture Research Station, Jumla and Marpha conduct research on apple varieties and other technical trials and recommend for cultivation practices. The farm produces apple saplings and sells to the farmers on demand basis. National Fruit Development Centre, Kirtipur prepares balance sheet of apple sapling for distribution to facilitate farmers' access to apple saplings, and monitors the fruit nurseries and farms/stations for quality saplings production.
7) Agro-Enterprise Center (AEC) supports in establishing market linkages and provides market price information.
8) Trade and Export Promotion Center (TEPC)/Ministry of Industry, Commerce and Supplies (MoICS) and FNCCI help promote business through policy lobbying, policy formulation and bilateral trade agreements.

[7] Based in discussion with Devon Jung Chaudhry, Dang.
[8] Based on discussion with Ram Krishna Chaulagain in Jumla, and Mr Niranjan Man Sherchan in Mustang.
[9] Based on discussions with Mr Prabal Sahi, a wholesale trader in Surkhet.

Table 2
Rainfall in the top districts for apple area during the last 37 years

Apple Growing District	Av. annual rainfall (mm)	Av. rainy days in a year	Av dry spell length in a year	CV of in annual rainfall	CV in annual rainy days	CV in annual dry spell length
Dolpa	601.9	51.1	98.9	46.9	38.7	44.0
Jumla	1063.5	88.4	62.4	14.5	17.5	32.5
Kalikot	773.2	67.3	60.6	19.5	16.9	34.4
Humla	737.2	62.5	69.5	26.4	30.5	32.4
Manang	412.2	48.3	61.5	25.7	22.3	26.8
Mugu	737.2	62.5	69.5	26.4	30.5	32.4
Mustang	140.2	13.9	135.4	79.3	59.8	55.5
Rukum	1717.9	81.3	63.2	21.4	16.1	24.6
Solukhumbu	1857.0	111.9	57.9	16.9	14.6	27.1

Note: Low-risk CV<25, high-risk CV >25–50, and very high-risk CV>50

B. *Adaptation Options for Climate Change*

The farmers' main choices are the improved varieties' resilience to the increased temperature, moisture stresses, and insect and diseases as the best way to adapt to CC at the production level. Adoption of technologies and practices to minimize the impact of increasing temperature at the transportation and storage stages are the main options for wholesale and retail markets.

C. *Climate Change in Major Districts of Apple Production*

An assessment of rainfall in the top districts for growing apple is presented in Table 2. In presenting the climate variables, the coefficient of variation (CV) in annual dry spell days is above 25 for all districts except Rukum. Mustang and Dolpa have a large coefficient of variation in annual rainfall, annual rainy days, and annual dry spell length.

The average annual temperature in the apple-growing districts has increased by 0.005 to 0.09 0C per year during the past 37 years. Future projection suggests that the temperature will increase by 2.4 0C by 2050. Likewise, the winter temperature, which is critical for apple cultivation, significantly increased in the past years and will continue to increase in the future. This increase in average annual and winter temperatures will push the apple-growing areas to higher altitudes. Farmers in the apple-growing areas have already experienced the impact of increased temperature in apple flowering and fruit bearing, which constitute an increase in the downside risks exposure of apple farmers.

Table 3
Impact of climate and other variables on apple yield

Variables	Apple yield (MT/ha)	
	coefficient	t-statics
Constant	9.14***	106.7
Average winter minimum temp _ºC	-0.003*	-4.0
Winter rainfall (Jan to May) _mm	-0.001*	-1.6
Area under a crop _ha	0.001***	4.6
Number of observations (N)	375	
F-statistics for degrees of freedom	(3, 371) =25.1***	
Coefficient of determination (Adj R^2)	0.1638	

Note: ***, * indicate significant at 1% and 10% levels, respectively.

The probability of drought during pre-monsoon is high in the apple-growing regions. In apple farming, pre-monsoon rainfall plays an important role in fruit bearing and quality of fruits. Severe to moderate drought during pre-monsoon causes moisture stress in apple trees where irrigation is limited. The probability of drought during monsoon is also high in the western apple-growing districts (Humla, Mugu, and Dolpa) and central mountains (Manang and Mustang).

D. *Estimates of VC Outputs without/with CC Effects*

The estimated aggregate losses due to CC of different products' VC with and without the CC for the years 2020 and 2030 are summarized in Table 4 below. It shows about 936 MT/year at the current level (2020).

This loss will increase to 10,257 MT/year by 2030 with increasing climatic risks and without adaptation conditions. CC-induced losses, particularly due to increasing temperature, in other VC nodes account for about 50% of the total postharvest loss in the VC. In terms of specific agricultural commodities, the CC induces a large amount of apple loss in the collection-grading-packaging, wholesale and retail section of the apple VC. This loss will increase to a large extent by 2030 with increasing climatic risks and without adaptation conditions. The total value of CC-induced loss in the apple VC is relatively high for farmers and retailers. Farmers incur a large reduction in apple production as well as an increasing cost of inputs. Retailers are another VC actor who suffers from CC impact on apple storage and distribution. Farmers cannot influence the market price of the apple; therefore, they have to absorb a large proportion of the cost of CC impact.

The CC would impact the level of consumption, production, and net trade of apples. The net trade of apples has been negatived for a long time. Domestic apple production growth will slow down under the CC; so, it will increase apple import from other countries. Net trade was -86,852 MT without CC and -87,788 MT with CC in 2020. This will substantially increase under both without and with CC scenario by 2030. The increasing negative net trade of apple is driven mainly by the increase in domestic consumption of apples with growth in average household income and tourism.

The above relation between outputs of other fruits/species and its ultimate impact on these products' net-trade with foreign counties also applies to other agricultural products. Therefore, the next sections deal with the climate suitability for and risks to the individual agricultural products.

CC Risks in Apple VC: Apple is grown in 54 districts in Nepal. However, there are only 12 major apple-producing districts mainly from the high mountain regions. Table 4 presents climate suitability for the apple VC. Temperature change has a major impact on all VC nodes. Changes in temperature and precipitation have a large impact also on input supply and apple production, and other the other VC nodes.

Table 4
Consumption, production, and trade of apple with/without CC impacts

Year	Consumption (Metric Ton)	Production (Metric Ton)		Net Trade (Metric Ton)	
		Without CC	With CC	Without CC	With CC
2020	121,543	34,691	33,755	-86,852	-87,788
2030	217,665	42,288	32,031	-175,377	-185,634

Table 5
Climate suitability for apple value chain (VC)

VC Node	Actors	Climate Suitability
Input supply	Nursery business/ agro-vets: Rootstock management to develop more adaptive varieties	Mean temperature during the active growing period 20–25 ^{0}C
Production	Apple farmers	Mean temperature during the active growing period is 20–25 ^{0}C. The optimum temperature for flower blossom and fruit set is 24 ^{0}C 1,000–1,500 hours (42–63 days) chilling below 7 ºC during winter to break dormancy These conditions are available at an elevation of 1,500–2,700 m asl
Collection, grading, packaging	Cooperatives, local/village traders, district traders	Freezing and chilling injury: Temperature drop frizzing point or very cold (<2 ºC) after harvest time (Aug-Sept) Heat injury: shelf life starts to decrease at temp >10 ºC after fruit harvest (Aug-Sept)
Processing	Apple processors	The lowest safe temperature for storage is 2-3 ºC. Shelf life starts to decrease at storage temp >10 ºC Post-harvest loss is 5%
Wholesale	City-based regional wholesalers (Nepalgunj, Pokhara, Kathmandu)	The lowest safe temperature for storage: 2–3 ºC Shelf life starts to decrease at temp >10 ºC
Retail	Regional and national markets, district markets	The lowest safe temperature for storage: 2–3 ºC Shelf life starts to decrease at storage or stall temp >10 ºC

Note: About 40 percent of the fruit loss occurred during the harvesting and postharvest handling period (Subedi et al., 2018).

Table 6
Climate Risks in Apple VC

VC Node	Actors	Climatic risks
Input Supply	Agro-Vets, Private apple nursery	Rootstock management to develop more adaptive varieties Increased demand for insecticide and pesticides Increased irrigation demand sapling planting (June–July)
Production	Apple farmers	Current varieties are less adaptive High irrigation demand, flowers drop due to acute water stress Fruit set drop in temperature above 25 ^{0}C High insect/pest incidence
Collection, grading, packaging	Cooperatives, Local/village traders, district traders	Increase in the loss in grading: sunburn and cracking, not appropriate color, insect paste damaged fruits, deformed shape and size Current loss: 5% at farm gate, 10% at collection centers (Subedi et al. 2018)
Processing	Apple processors	Increased demand for high-quality fruits Increased cost of storage
Wholesale	City-based regional wholesalers (Nepalgunj, Pokhara, Kathmandu)	Increase in storage costs (cold storage) Increase in fruit loss due to increased temperature (current loss: 5%)
Retail	Regional and national markets, district markets	Increase in storage costs (cold storage) Increase in fruit loss due to increased temperature (current loss: 20%)

CC in the core apple production regions is projected to -increase warming, a shift in seasonality, and a variation in annual and seasonal rainfall. The most damages from CC to apple production are a significant reduction in winter chilling, increased heat stress, shortages of water supply, increased postharvest losses, and increasing risks of hailstorms and pest/disease outbreaks. Shifts in flowering and harvest dates of apples in the mountain regions have gradually disrupted marketing windows and activities across the supply VC. A warmer climate also increases the demand for and cost of inputs (improved varieties, insect/disease control, and irrigation), grading and packaging, cold storage, processing, and cooling on retailer shelves.

Table 5 presents climate-related risks in the apple VC in Nepal. Key CC risks at the input supply include rootstock management to develop adaptive apple varieties to a warmer and dry climate in the mountain regions, timely supply of insecticides and pesticides, and management of increased irrigation demand for apple sapling nurseries. These risks imply an increase in the cost of inputs for apple production. Similar risks are also observed by apple farmers in the form of a gradual decline in apple yield (ton/ha), increasing incidence of insect and new diseases, and water stress with increasing dry days. Increasing incidences of hailstorm in the eastern hills are also destroying apple crops, resulting in a decrease in production. Farmers' cooperatives, local/village, and district traders are involved in the collection, grading, and packaging of apples before trading from the production locations. These VC actors lose a certain amount of apples due to CC impacts at the production level. CC decreases the quality of apple with deformed shape and size of fruits that lead to a huge loss in grading and processing.

Impact of climate risks: A more direct and large CC impact exists at the production node of the apple VC. The results of regression analysis in Table 5.2 above show that the yield of apples (MT/Ha) will decline with a coefficient of -0.003 if the average minimum temperature rises by one degree centigrade. This relationship may be attributed to a lack of chilling hours

Table 7
Cost of adaptation at the production level of apple VC (literature survey)

Crop	Adaptation options	Cost (NPR per ha)
Apple[1]	Orchard replacement with improved sapling—resilient to CC, insects, and diseases	9,900–13,200
	Water conservation—to minimize moisture stress	2,600–3,500
	Mulching and irrigation—to minimize moisture stress	1,500- 4,125
	Plant protection chemicals	2,500–3,000

Table 8
Impact of cost of CC on VC nodes and adaptation options

Crop	VC node	Impact	Adaptation options
Apple	Collection-grading-packaging	Freezing and chilling injury: Temperature drop frizzing point or very cold (<2 ºC) after fruit harvest (Aug–Sept) Heat injury: Shelf life starts to decrease at temp >10 ºC after fruit harvest (Aug–Sept)	Avoid freezing and chilling temperature
	Wholesale and Retail	Shelf life starts to decrease at temp >10 ºC Low shelf life in the retail shop	Avoid high temperature with precooling under the shade waxing
	Regional and national markets	Storage loss due to high temperature and humidity condition	Store at 4.5–12.8 ºC temperature Reduce duration of storage

due to rise in temperature. Similarly, the productivity of apple will decline with coefficient -0.001 if the rainfall in the winter season (January–May) rises by one millimetre. It may be because the apple plants expect snow and not rain during the winter season. Rain is helpful during the flowering time. On the other hand, the productivity of apple will increase by 0.001 if the apple-growing area increases by one hectare. The latter may be a reflection of economies of scale in apple cultivation. The above-mentioned CC impacts on production spill over to other VC nodes via price changes and the cost of reducing climatic risks in the collection-grading-packaging, wholesale, and retail sections of the apple VC.

E. Socio-Economic and Financial Analysis of CC Adoption Options

Cost of adaptation at the production level: SNV (2011) did some studies on changes in the cost of production of apples. They identified the need for gradual replacement of the current less adaptive varieties with improved, climate-resilient, and insects and disease - resistant varieties. Based on this literature, Table 6 presents the cost of replacement of current varieties. In addition, the CC also increases cost of water management in apple crop. Similarly, the cost of plant protection chemicals increases with the increasing incidence of insect and disease damages under CC. The overall cost to farmers increases towards adapting the technology for CC and minimizing losses. The cost of adaptation varies across the agro-ecological regions and with methods of application. Generally, a combination of adaptation options outperforms a single option for CC adaptation at the production stage of the VCs.

[1]Cost of adaptation differs based on apple-growing regions. Cost is high in the central region (Mustang and Manang) as compared to the western (Jumla/Humla) and eastern (Solukhumbu) regions.

Cost of adaptation at the other VC nodes: Maintaining the long shelf life of apples is important under CC. Apple is climacteric fruits that can be harvested at a certain level of maturity and stored for a long time under certain temperature and humidity. Temperature below or above the optimum for storage can damage the fruit and reduce the shelf life of the fruits. Table 7 presents the impact of CC on VC nodes, and adaptation options. The cost of CC-induced losses in the VC cannot be measured easily. VC losses depend on various factors such as duration of exposure to the outside temperature, damage during transportation, moisture content in the fruits. This study recommends key adaptation options in the VC nodes of apple.

Yield Levels, and Sensitivity of Yields and Costs to CC of Apple: Productivity of apples in Nepal was 7.22 MT/ha: the yield is slightly lower than Jumla district (7.08 MT/ha) but it is much higher in Mustang district (12.87 MT per ha) (MoALD, 2020). In other words, Mustang apples have comparative advantage due to higher productivity of apples; and as Jumla apples have lower productivity of apples, this district has scope for improving the productivity. At the national level, Poor adoption level of improved agricultural practices and modern technologies is a major problem in apple production in Nepal. Dormant shoot pruning in apple maintains shape and size of tree canopy, increases yield and vigour, and improves the quality of produce (Magga, 1965). Adoption of good agricultural practices and efficient utilization of resources can increase apple production and reduce trade deficit (Subedi et al., 2018). Apple is a highly climate sensitive fruit, and its yield can be lost/reduced up to 22% due to CC if no any intervention strategy is adopted at the farm level. [10] Grafted Fuji variety of apple is found to be climate resilient in Nepal. A total of 300 saplings of apple are grown in one hectare land. The yield of apple can start from the fifth year after plantation (900 kg per ha), and potential yield is gained within 15 years (16,500 kg per ha). The total apple fruit production over the life span of 15 years is 92.4 MT from one hectare of land, and the total revenue is NPR[11] 7,392,000 over 15 years (492,800/year), with a net total profit of 3,223,024 Nepali rupees. At a discounted rate of 12% and a total life span of 15 years, the benefit-cost ratio (B/C) is about 2.0 (Refer Figure (Refer Figure 2) be 8%. Some parameters like IRR are found to be less than the required rate of return when analyzed in 15 years period as opposed to (more than) 40 years which is the actual economic life of apple tree.

[10] Projection based on CC impact model, FGDs with farmers ad KII with concerned stakeholders

[11] 133 NPR (Nepalese Rupees) = 1 US Doller

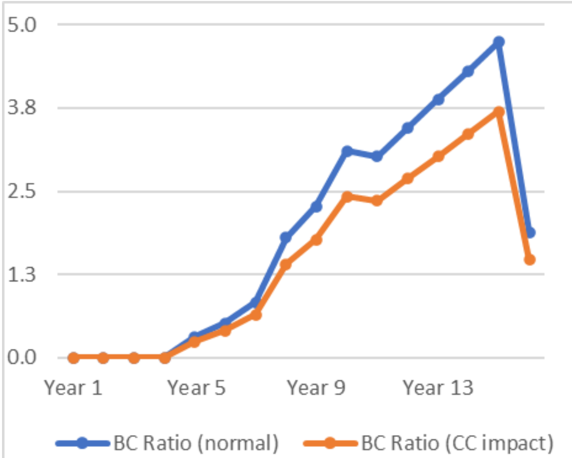

Fig. 2. B/C ratio of apple farming at normal and climate change scenario (in 1 ha land)

Notes: (i) Benefit-cost ratio (BCR) is calculated based on a field survey from February–March, 2021 at production sites and different market nodes. (ii) The baseline is the normal scenario of BCR without CC impact and CC impact at different VC nodes identified during the survey period, and negative impact has been estimated.

Table 9
Benefit Cost ratio at different VC nodes of apple

Apple Crop and VC Nodes	B/C Ratio	
	Baseline	With CC
Farm nursery	2.08	1.89
Farm production	1.90	1.50
Storage-cold store	1.53	1.39
Agro-processing	1.33	1.21
Assemblers' local trade	1.10	0.99

4. Conclusion and Policy Implication

Apple, the 'queen' of fruits, would be most seriously affected by rise in winter temperature, precipitation and onset of natural disasters. Apple harvesting area, yield, and output grew by 1.98%, 0.53% and 2.51% linearly during 1990-2019. Overall, the BCR of apple VC (simple average of BCR over the VC nodes namely the nursery, farm production, assemblers' local trade, cold storage, and agro-processing) would fall from 1.59 to 1.40 due to the impact of climate change. In order to off-set theses losses, the compensating finance required for these CC adaptation technologies would be NPR 350,000 per hectare for high density plantation (like Fuji), pest, irrigation and orchard management. The ways forward for the apple value chain to manage the climate change adaptation and mitigation (CCA/M) aspects would be as follows.

i. *Variety and seeds:* There is a lot of interest to improve the quality of saplings, and new verities of apple in Jumla and Mustang. Government should monitor the quality of saplings of traditional varieties of apples from the local nursery for plant health and safety; provide the 'Fuji', M or MM series of variety saplings; release the Canadian-spur types and French-spur types of apples soon to the farmers; and establish a tissue culture laboratory. These will help promote varieties with low chilling period requirement, early-/late fruiting variety, and black frost-resistant genomes.

ii. *Farm inputs and production:* Apples can contribute in family incomes higher than the current rate of 20%. Farmers' responses to apple production/supply have been 0.804 with respect to the producers' prices. Jumla apples are organic by default, but organic technology is hardly available. There is acute shortage of plant nutrients and, above all, water. So, it is important to provide support for water conservation, rain harvesting, snow-harvesting, ground water recharge, and piped irrigation. The government must ensure good road and transport, electricity supply and communication networks for increasing the access to the farm output suppliers, and lower the prices for farm input users.

iii. *Agri-Marketing:* Farmers do not have collection centres/warehouses in the village, have no information about prices except from the traders, and they transport apples in *doko*. The quantity of apple losses during transportation is about 5–10% of the cargo. The government's 'Apple Self-Sufficiency Program' would be unthinkable without a visible priority to develop the shorter and safe road networks throughout the west-to-far west mountain regions for linking the apple production pockets with national markets, and develop a rapid, safe containerized transport.

iv. *Apple-based agro-industrial processing:* CC and expansion of apple farms would inevitably produce more apple worthy of processing for wine, brandy, etc. The loss of apple due to poor storage is high (5%). Apple processing has recently begun in Jumla and Mustang with a capacity of little over 300,000 litres of beverage, but it needs to grow to pull-up the apple farming and meet the consumers' demand. Authorities must support to prevent decline in production of the local varieties of apple to ease increasing scarcity of raw materials (Fuji variety, etc., are costly); support apple processing firms with renewable energy; and finance the development of GMP, including HACCP.

v. *Cold storage and wholesale trade:* Keeping the quality of Nepali apples as fresh is possible for only about two to three months whereas it should have been about eight to nine months foe catering as per its demand in the markets. Goods are transported from the origins in the hinterlands to Dang in ordinary containers, which increases the temperature causing losses during transportation (about 4.44%). Cold chains need viable cold storage units, but they are underused. There is a need to develop containerized clod-chain transport, improve the management of cellar stores in the production pockets, and reduce the electricity tariffs for the cold stores and chains.

vi. *Foreign trade:* Competitiveness of Karnali apples vis-a-vis foreign apples is questionable whereas the Mustang apple seems to be competitive with foreign apples, but it has limited volume due to small area, low adoption and yield gaps. The government needs to intensify its apple development program with an emphasis on the internationally competitive varieties with respect to their yield, quality, SPS issues, harvesting schedules, and raw materials for agro-industrial processing, and developing a brand of Nepalese apple and popularize it in foreign markets.

vii. *Retail trading, consumer preferences:* Seasonal variations in quantity and prices are high. Consumers' demands for apples are inelastic with prices (e= -0.194), and their preferences for domestic apples over the foreign apples are unclear. Supermarkets need to source the niche products from producers, e.g., Jumla organic apples; civil societies must launch consumer awareness activities about the responsibility to prefer the national products over the imported ones.

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