Optimizing water use in the Central Highlands of Viet Nam

Focus on the Robusta coffee sector

Dr. Dave A. D’haeze

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Back cover photo: The landscape of a coffee plantation in the Central Highlands, Viet Nam © Alisher Sharipau, Hanns R. Neumann Stiftung

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Table of contents

List of tables

List of figures

1. Abbreviations, acronyms, units and currency

1.1 Abbreviations and Acronyms

BaU	Business as Usual
bil	billion
BRIDGE	Building River Dialogue and Governance
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station data
gbe	green bean equivalent
ha	hectare
IUCN	International Union for Conservation of Nature and Natural Resources
mio	million
NDVI	Normalized Difference Vegetation Index
NIAPP	National Institute for Planning and Projection
ROI	Return on Investment
SPI	Standard Precipitation Index
t	metric ton
USD	United States Dollars
VND	Vietnam Dong
WASI	Western Highlands Agriculture and Forestry Science Institute
y	year

1.2 Metrics

This report makes use of the International System of Units (SI).

1.3 Currency

Raw calculations were done in Vietnam Dong and converted to USD at an exchange rate of 22,949 VND for 1 USD.

2. Introduction

International Union for Conservation of Nature and Natural Resources (IUCN), through its BRIDGE program (Building River Dialogue and Governance), is supporting work on transboundary river cooperation in the 3S (i.e. Srepok, Sesan and Sekong) river basins. Coffee is the dominant commercial land use and a major user of water in the Central Highlands of Vietnam, which forms the headwaters of the Srepok and Sesan (2S) Rivers.

In 2019, a rapid assessment of opportunities was conducted to transition coffee monocultures into diversified coffee farming with significant benefits in terms of total crop value, drought resilience, existing coffee supply to the global market and dry season water availability and downstream flows. The analysis showed that more efficient irrigation and the transition of drought prone areas out of coffee and into high value tree crops could increase the dry season flow of the 2S by 50% with potentially substantial downstream and transboundary benefits.

The assessment was updated in 2020: https://www.iucn.org/news/viet-nam/202008/transforming-coffee-and-water-use-central-highlands-vietnam-case-study-dak-lak-province.

There is growing business interest in such transition to reduce the risk of farmers abandoning coffee altogether under conditions in increasing weather variability, thereby threatening supply chains, and to ensure compliance with increasingly strict international regulations on pesticide residues. See: https://www.iucn.org/news/viet-nam/202010/business-consultation-coffee-transformation-and-water-use-vietnams-central-highlands.

Building on the 2020 assessment, the objective of this assignment is to provide a more detailed analysis of the costs and benefits of the proposed transition from coffee monocultures into diverse, higher value, and water saving agroforestry across all five provinces in the Central Highlands.

The goal of this study is to:

1. Identify areas suitable for coffee production the five Central Highlands provinces in terms of soil/topography.
2. Identify areas with a potential water shortage in extreme dry years for the December-May dry season by looking at the monthly Standard Precipitation Index and the Normalized Difference Vegetation Index derived from satellite imagery, over a 20-years period.
3. Run the crop diversification model developed for Dak Lak for the entire Central Highlands:
    a. Scenario 1: Business as usual (BaU) i.e. rejuvenate monocrop coffee over 19 years in all current coffee areas.
    b. Scenario 2: Diversify coffee with pepper, avocado and durian on land units suitable for coffee and replace coffee with a combination of aforementioned crops on water scarce land units.
4. Refine the economic analysis at farm level; i.e. use Monte Carlo simulation to quantify the probability and value as well as farmers' risk exposure to gross revenue loss/profit for the intercrop model vs. the current situation.
5. Summarize all above results broken down per province (investment needs for transition per province is important for provincial decision makers).

This analysis differs from the initial rapid assessment in the following ways:

a. The report covers all 5 provinces of the Central Highlands (i.e. Kon Tum, Gia Lai, Dak Lak, Dak Nong and Lam Dong). Looking at the study from an administrative boundary perspective may facilitate decision making at provincial level.
b. The modelling timeframe has been set at 30 years so as to include the full life cycle of Robusta coffee (i.e. 25 years).
c. The analysis is done at both the landscape level and the individual farm level. The landscape level is important to understand, e.g. total provincial production of coffee and intercrops or to better capture regional water savings. The farm level analysis on the other hand allows us to assess farm income and investment needs at the individual level.
d. The report includes a return on investment (ROI) analysis to help the public and private sector understand the cost and benefits of a large-scale intervention strategy. At the farm level, the ROI analysis can help convince farmers shifting to the new business model and allows to estimate farm financing needs (if any).
e. The report includes a quick assessment of potential carbon sequestration in view of changing climate conditions.

The report is structured as follows. At first the rationale for this study is elaborated. The methodology and data used in this report are then described. In the following chapter (results) different options for agricultural transformation are analyzed in terms of coffee production, water saving, profitability and climate change mitigation both at the landscape and farm level. Finally, conclusions and recommendations are presented.

3. Background

Vietnam is the world's second largest coffee producer and leading Robusta coffee exporter. The country achieves the world's highest coffee yields which puts it in the center of the global coffee market as demand is constantly increasing (1-3% per year). Coffee is the most important agricultural export product in value for Vietnam and supporting the rural livelihoods of over 2 million people, mainly in the Central Highlands. Export volumes peaked at 30 million bags in 2018 generating revenues of 3.54 billion USD.

The Central Highlands has a population of circa 5.7 million (GSO, 2016). It is the second poorest region in Viet Nam and rural poverty is almost double the national average (28.8% vs. 17.9%) with particularly high poverty rates among ethnic minorities who make up 32% of the population. Over 40% of the Central Highlands' population earns an income from coffee production.

In order to make coffee farming economically viable, irrigation is needed to achieve yields that average 2.3 tons of green beans per ha (ICO, 2019). However, people living in the Central Highlands increasingly face the challenges of drought and extreme water shortage. These threaten agricultural production, which not only affects community life but also weakens the local economy (ICEM, 2013). E.g. as a result of the 2016 drought, the discharge of main rivers reduced by 20-90% (NCHMF, 2016). The same year, about 70% of the cultivation area experienced severe drought (MARD, 2016). Nearly 170,000 ha of crops were affected by the drought, of which 7,100 ha were left fallow and more than 95,000 ha were deficient in irrigation (CGIAR, 2016).

Aggravating this situation is the absence of systematic monitoring of water resources, which makes it impossible to provide information on the condition of water resources and recommend a course of action on water resources management for the region.

During the dry months (January-April) Robusta coffee in Vietnam needs to be irrigated. Although water is scare during this period, smallholder coffee farmers tend to irrigate up to 2 times more than what MARD recommends. Over-extraction can be explained by the fact that water is an open access resource, has no price and licensing regulations about the maximum number of wells and their maximum extraction depth are not enforced.

During the 2016 drought, CGIAR experts conducted a rapid appraisal on how to cope with climate change and water scarcity in agriculture and made the following recommendation to MARD: "*Develop appropriate policies to encourage diversification of agricultural systems, including innovative financing mechanisms to support smallholders."* The authors argue that: *"Changing land use patterns and landscape management are options for long-term adaptation. Typical monocultures in the Central Highlands could be replaced with diversified cropping systems, which vary agricultural products (both cultivation and livestock). These diversified systems engender multiple sources of household income and promote resilience to climate change and extreme weather events."*

Aligned with the above recommendations, this report presents a macro-economic landscape and farm level analysis for transforming coffee monocrop into diversified farming systems.

4. Materials and methods

4.1 Study area

The study area is the Central Highlands (Figure 4.1) which is comprised of 5 provinces, from north to south, Kon Tum, Gia Lai, Dak Lak, Dak Nong and Lam Dong. The current coffee area in this region was estimated at 586,000 ha based on SPOT satellite imagery (NIAPP, 2015).

To address agricultural transformation needs in response to climate change, it is important to understand land suitability for the Robusta coffee in terms of soil and landscape characteristics (e.g. topography) as well as water availability for irrigation during the dry season. In an earlier IUCN report on Dak Lak Province (D'haeze, 2020), water scarce coffee areas were identified based on a geohydrological study by Milnes et al. (2015). Since this information is not available for the entire Central Highlands, this study relies on time series satellite imagery to identify drought prone areas using the Standard Precipitation Index (SPI) and to assess crop vegetative response using the Normalized Difference Vegetation Index (NDVI).

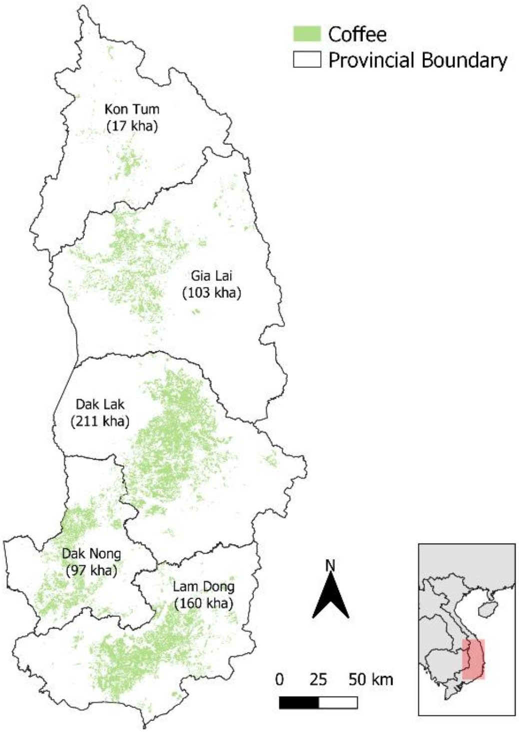

Figure 4.1 Coffee area in the Central Highlands

4.2 Identification of drought prone coffee areas

4.2.1 Spatiotemporal drought analysis

A commonly used indicator to identify the severity of drought events, recommended by the World Meteorological Organization, is the Standard Precipitation Index (SPI). SPI is a normalized, dimensionless index representing the probability of occurrence of an observed rainfall amount when compared with the long-term median rainfall at a certain geographical location. Negative SPI values represent rainfall deficit, whereas positive SPI values indicate rainfall surplus. The intensity of drought events can be classified according to the magnitude of negative SPI values (Table 4.1). For example, a negative SPI value greater than 2 is classified as extremely dry. SPI also enables rainfall conditions to be quantified over different time scales (e.g. 3, 6, 12 or 24-months), facilitating the analyses of drought impact on various water resource needs. For example, SPI3 applied in this study, measures rainfall conditions over a 3-month period, the anomalies of which impact mostly soil water conditions and agricultural produce.

Table 4.1 Classification of the Standard Precipitation Index

Value					**Precipitation Regime**
2.0	<	SPI	<=	max	extremely wet
1.5	<	SPI	<=	2.0	very wet
1.0	<	SPI	<=	1.5	moderately wet
-1.0	<	SPI	<=	1.0	normal precipitation
-1.5	<	SPI	<=	-1.0	moderately dry
-2.0	<	SPI	<=	-1.5	very dry
min	<	SPI	<=	-2.0	extremely dry

Monthly CHIRPS (Climate Hazards Group InfraRed Precipitation with Station data) satellite images (Figure 4.2) were used for a period of 20 years (2001-2020). CHIRPS is a 35-year quasi-global rainfall data set, which is available in different time steps at a spatial resolution of 0.05° (~ 5 by 5 km). The data can be freely downloaded at https://data.chc.ucsb.edu/products/CHIRPS-2.0/. Using freeware software packages QGIS 2.16 and R Studio 1.4.1717, the SPI3 was calculated pixel by pixel for a 20-years monthly time series[1] of CHIRPS rainfall records (Figure 4.3).

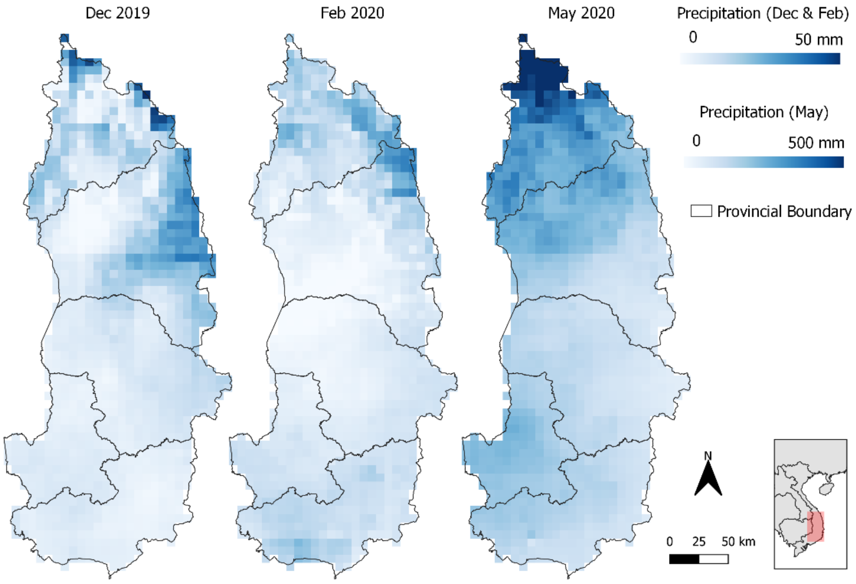

Figure 4.2 Spatio-temporal precipitation trends in the 2019/2020 dry season in the Central Highlands

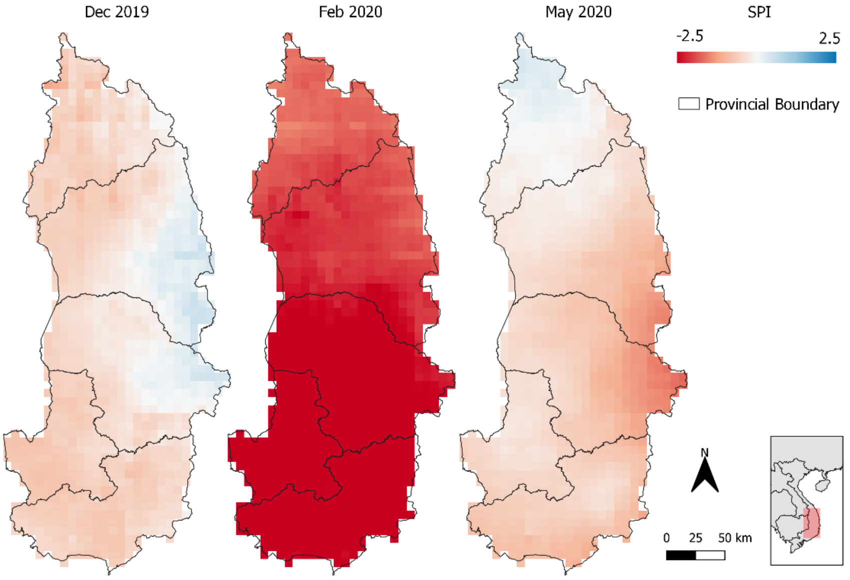

Figure 4.3 Spatio-temporal SPI3 trends in the 2019/2020 dry season in the Central Highlands

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[1] Figures 4.2 and 4.3 above are presented as an example only to show trends. These maps are part of a full time series that consists of 240 maps for rainfall and SPI each (monthly data over 20 years).

Figure 4.4 shows the monthly average SPI3 for the entire Central Highlands over 20 years and indicates that in order of drought severity 2005, 2014 and 2020 were the most critical years. Table 4.2 summarizes the observed SPI3 values for the three driest years.

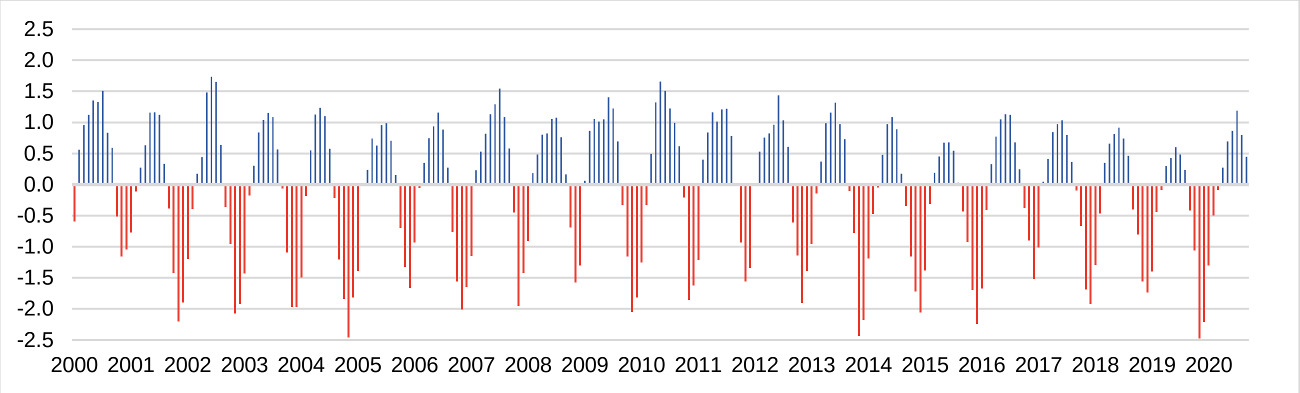

Figure 4.4 Average monthly SPI3 for the entire Central Highlands

Red bars below 1.0 indicate drought and blue bars higher than 1.0 show above average precipitation.

Table 4.2 SPI3 per month for the driest years

The highlighted cells show moderately dry months (SPI3 < 1.0); cells with a red border indicate extremely dry months (SPI3 <2.0).

Month	2004/2005	2013/2014	2019/2020
Nov	-0.22	0.73	0.23
Dec	-1.20	-0.10	-0.41
Jan	-1.84	-0.78	-1.06
Feb	-2.45	-2.43	-2.48
Mar	-1.81	-2.17	-2.21
Apr	-1.39	-1.19	-1.30
May	-0.02	-0.47	-0.50
Jun	0.24	-0.04	-0.09
Total dry	-8.93	-7.18	-8.04

4.2.2 Spatio-temporal vegetative crop response analysis

Since coffee in the Central Highlands is irrigated, land suitability highly depends on water accessibility during the dry season. In case of water scarcity, the trees will start dehydrating and may in extreme cases die. This vegetative plant response in relation to water availability can be monitored with the Normalized Difference Vegetation Index (NDVI), which measures the difference between near-infrared (which healthy vegetation strongly reflects) and red light (which healthy vegetation absorbs). The NDVI can have a value between -1 and 1. Values below 0 are classified as water bodies or clouds, values between 0 and 0.2 are bare or rock land and values above 0.2 depict vegetation. The higher the NDVI value the healthier/greener the vegetation.

MODIS NDVI satellite data are used. They have a spatial resolution of 250 by 250 m, are available on a 16-day interval and can be downloaded for free at https://modis.gsfc.nasa.gov/data/dataprod/mod13.php. Figure 4.5 shows the NDVI trends over time in 2019/2020. For example, in Dak Lak, coffee areas in the east appear clearly affected by water scarcity in February (red), while in the center of the basalt plateau the NDVI values remain rather stable (greenish) indicating sufficient water availability (less plant water stress).

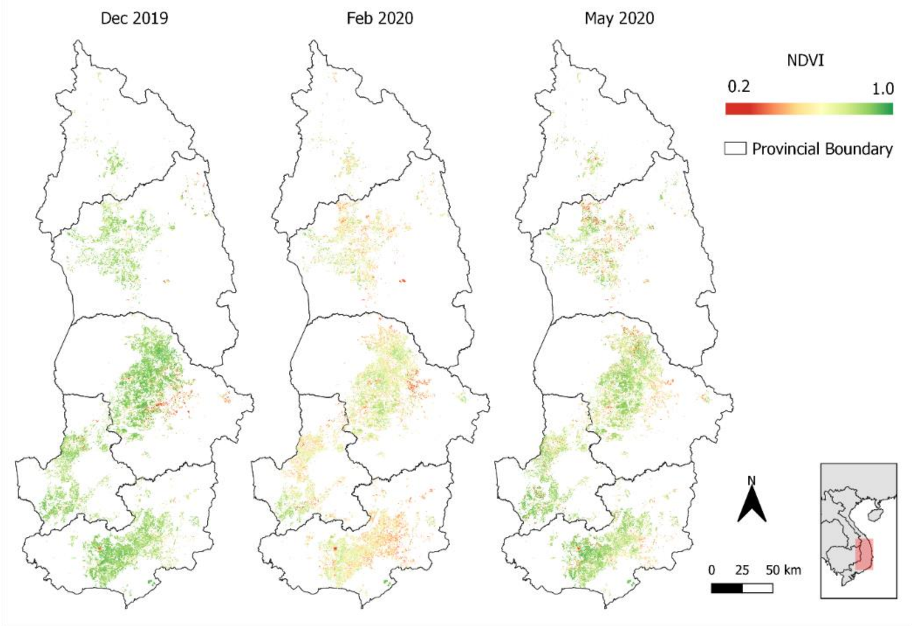

Figure 4.5 Spatio-temporal NDVI variation in the 2019/2020 dry season in coffee areas

To understand plant response in relation to water availability, a spatio-temporal NDVI trend analysis was done using the modified Mann-Kendall method to derive the Sen slope (i.e. the trend direction) and its significance (p value). Applying freeware software packages QGIS 2.16 and R Studio 1.4.1717, the trend analysis was done pixel by pixel for the three driest years (i.e. 2005, 2014 and 2020) and for the dry season months only (i.e. December in the previous year till May in the current year; i.e. 2 images/month x 6 months = 12 images/year). It is assumed that the NDVI will remain stable or show a slight decline during the dry season in irrigated areas with sufficient water availability, while the NDVI will significantly decline (plant wilting) towards the end of the dry season in areas with water scarcity. Figure 4.6 shows the NDVI trend during the dry season in the three driest years. In 2020, coffee trees in Gia Lai, Dak Lak and northern Dak Nong appeared suffering more from water stress (red), compared to Lam Dong province (bluish).

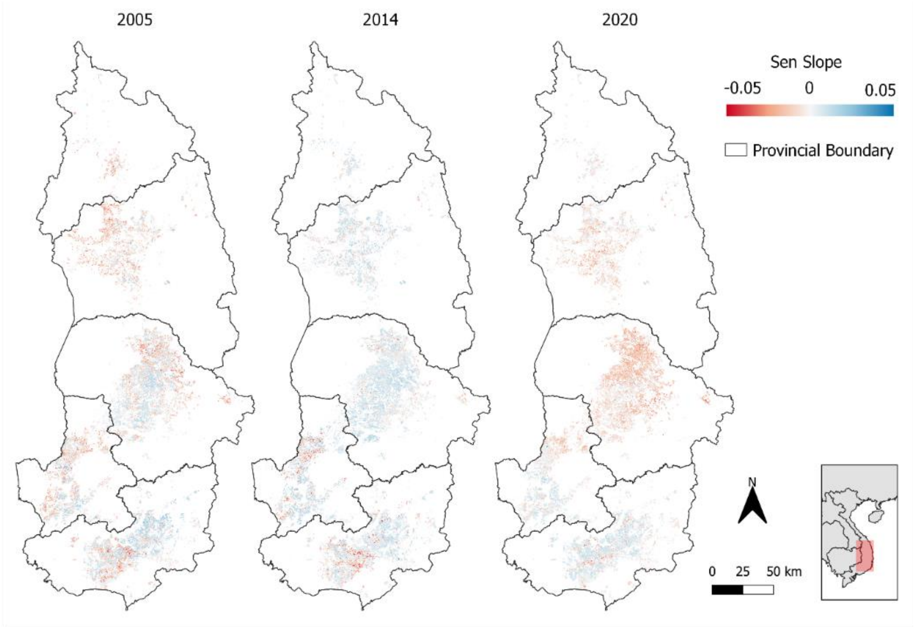

Figure 4.6 Spatio-temporal Sen slope variation for the driest years (2005, 2014 and 2020) in coffee areas

On top of the trend analysis, the difference between the NDVI value in May and December was studied ($NDVI_{diff} = NDVI_{May} - NDVI_{Dec}$). Negative $NDVI_{diff}$ values indicate plant wilting (i.e. water scarcity), while positive values show vegetative plant recovery in May as compared to the start of the dry season in December (Figure 4.7).

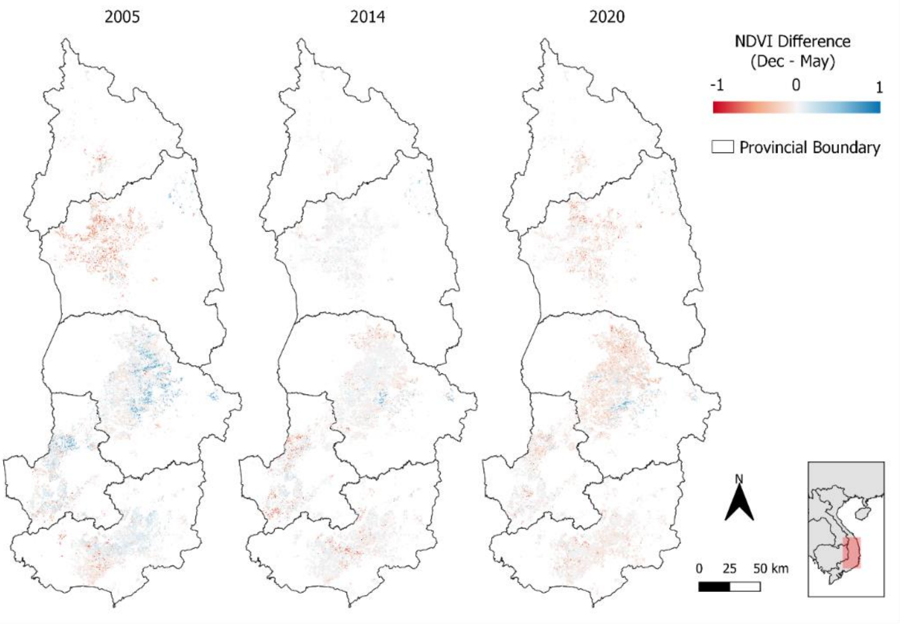

Figure 4.7 Spatio-temporal $NDVI_{diff}$ variation for the driest years (2005, 2014 and 2020) in coffee areas

$NDVI_{diff}$ is dimensionless indicator expressing the difference between $NDVI_{May}$ and $NDVI_{Dec}$.

4.2.3 Water scarce coffee areas

Combining the results of the meteorological drought and vegetative crop response analyses allows us to identify areas at risk of severe water shortage during the dry season. For each extremely dry year (2005, 2014 and 2020), coffee areas with a significant negative NDVI trend (i.e. statistically significant negative Sen slope at $p<0.05$) and having a net negative $NDVI_{diff}$ value, were identified. Aggregating the three years (since water scarcity may vary spatially year by year depending on precipitation), results in a proxy layer representing potentially water scarce coffee areas (Figure 4.8, map 1). In 2015, Milnes et al. conducted a geohydrological study on the basalt plateau in Dak Lak and identified water scarce areas based on groundwater availability (Figure 4.8, map 2). This layer of information was aggregated with the results from this study based on SPI3 and NDVI analysis, to generate the water scarcity map for the entire Central Highlands (Figure 4.8, map at the right).

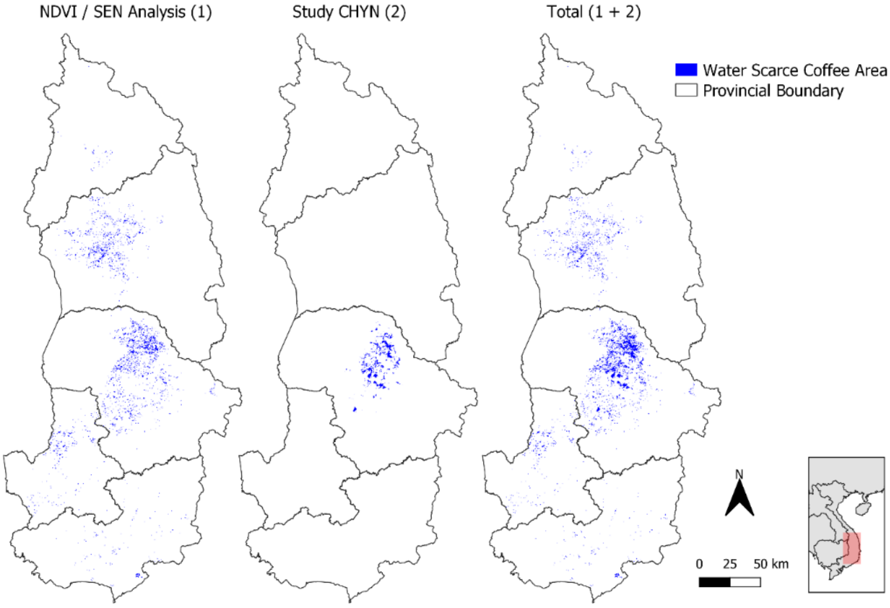

Figure 4.8 Water scarce coffee areas

4.3 Current land use and land suitability for Robusta Coffee

The current coffee area in the Central Highlands was estimated based on SPOT satellite imagery (NIAPP, 2015). This map was overlain with the physical land suitability map[2] (NIAPP & KUL, 2002) and the water scarcity map (CHYN, 2015 and current study) to identify suitable and unsuitable land units in terms of water scarcity, soil and topographic conditions (Figure 4.9 and Table 4.3).

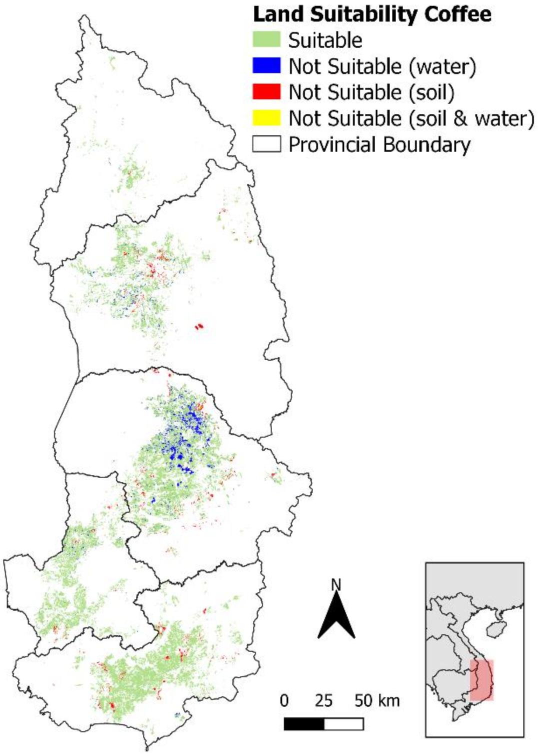

Figure 4.9 Land suitability for coffee production in the Central Highlands

Table 4.3 Land suitability for coffee per province

Province	Suitability	ha	%
Kon Tum	total	16,576	
	suitable	16,141	97
	not suitable (water)	214	1
	not suitable (soil)	221	1
	not suitable (soil & water)	-	0
Gia Lai	total	103,180	
	suitable	92,418	90
	not suitable (water)	4,915	5
	not suitable (soil)	5,518	5
	not suitable (soil & water)	329	0
Dak Lak	total	210,948	
	suitable	179,311	85
	not suitable (water)	24,904	12
	not suitable (soil)	6,131	3
	not suitable (soil & water)	601	0
Dak Nong	total	96,557	
	suitable	93,100	96
	not suitable (water)	1,718	2
	not suitable (soil)	1,717	2
	not suitable (soil & water)	23	0
Lam Dong	total	158,941	
	suitable	150,918	95
	not suitable (water)	739	0
	not suitable (soil)	7,256	5
	not suitable (soil & water)	28	0

Table 4.3 summarizes the land evaluation exercise above. In total ~586,000 ha is planted with coffee of which ~532,000 ha are suitable (91%). Areas not suitable for coffee production in terms of soil and topographic conditions count ~22,000 ha (4%). These land units will be excluded from the macro-economic modeling below. Areas unsuitable for coffee only because of seasonal water scarcity sum up to ~32,500 ha (6%). These land units will be included in the landscape model but converted into less water demanding mixed cropping systems without coffee.

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[2] The land suitability map was developed in the Belgian VLIR-DGOS project "Land Evaluation for Land Use Planning and Development of Sustainable Agriculture in South-Vietnam". This was a cooperation between the Katholieke Universiteit Leuven (KUL, Catholic University Leuven, Belgium) and the National Institute for Planning and Projection (Vietnam). The project ran from 1997 till 2002.

4.4 Crop water requirements and current actual water use

4.4.1 Robusta coffee

Empirical research shows that the maximum required irrigation volume per coffee tree per round is ~400 liters for hose irrigation (D'haeze, 2003).

A recent study (Viossanges et al., 2019, IWMI/Nestlé/SDC project report[3]) found that farmers in the Central Highlands in general and in Dak Lak in particular appear to be shifting from traditional hose irrigation to overhead sprinkler to save labor time and costs (Figure 4.10). To calculate the landscape wide water requirement, the irrigation method needs to be factored in as some methods are more or less efficient than others.

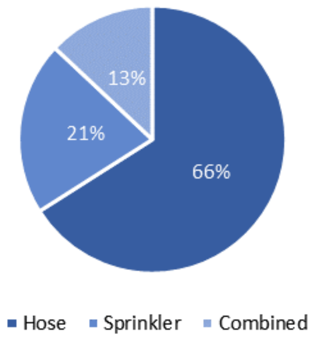

Figure 4.10 Most common irrigation methods in the Central Highlands

Based on a survey sample of 14,592 coffee farmers in Gia Lai, Dak Lak, Dak Nong and Lam Dong (2017). 'Combined' refers to the use of both hose and overhead sprinkler on the same farm.

For hose irrigation, water is conveyed directly from the source to the individual coffee tree without significant losses. Hence the crop water requirement of 400 l/tree/round is equal to the water extraction volume. Assuming that the dimensions of each basin around an individual coffee tree are 2.5 by 2.5 m, then the wetted soil surface is 6.25 m^2. For overhead sprinkler the entire field is wetted. Given the plant spacing of 3 m by 3 m (1,110 trees / ha), this is equivalent to 9 m^2 per tree. Therefore, without considering evaporative water losses on the canopy, the sprinkler method requires about 45% more water i.e. ~600 l/tree/round (Table 4.4).

Table 4.4 Summary of current and optimal water requirement for coffee

The water requirements are broken down per irrigation method.
The upper part of the table shows figures in l/tree/round, while in the lower part these figures are converted to m^3/ha.
The values per ha assume 1,110 coffee trees/ha and 3 irrigation rounds per year.

Item	Unit	Hose	Sprinkler	Combined	Weighted average
Percent users by irrigation method	%	66%	21%	13%	
Current irrigation volume	l/tree/round	585	689	637	614
Recommended irrigation volume	l/tree/round	400	600	500	455
Potential water saving	l/tree/round	185	89	137	159
Current irrigation volume	m^3/ha	1,948	2,294	2,121	2,043
Recommended irrigation volume	m^3/ha	1,332	1,998	1,665	1,515
Potential water saving	m^3/ha	616	296	456	528

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[3] The project "Viet Nam to produce more coffee with less water - towards a reduction of the blue water footprint in coffee production" was co-financed by Nestlé/Nescafé and the Swiss Agency for Development and Cooperation. Implementation was with the foundation Hanns R. Neumann Stiftung. The project duration was 5 years (2014-2019).

In the above-mentioned Nestlé/SDC project, irrigation application measurements were conducted in 2017, 2018 and 2019 for a sample of ~ 400 farmers. This is statistically representative for a population size of 586,000 farming households (equivalent to all coffee farmers in the Central Highlands). The measurements were broken down per irrigation method and whether farmers received project training or not. Results show adoption rates of 55% and 53% for respectively hose and overhead sprinkler irrigation (Figure 4.11 and Figure 4.12).

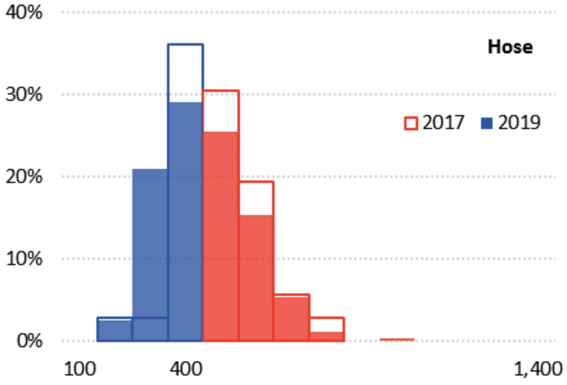


Figure 4.11 Adoption rates of good irrigation practices in 2017 and 2019 (hose)

The x-axis shows the applied irrigation volume (l/tree/ha). The y-axis indicates the number of farmers applying a certain volume of water (%).
The sum of the blue full colored bars shows a 55% adoption rate in 2019 (irrigation volume less than 400 l/tree/round).

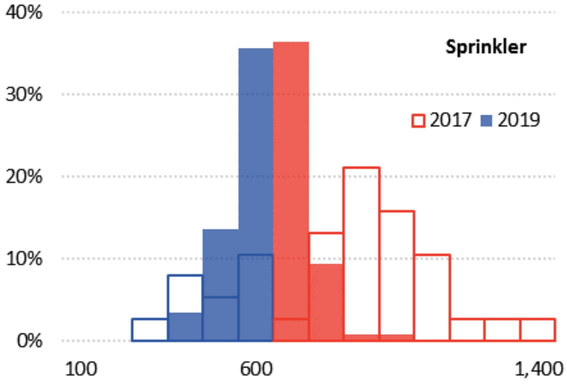


Figure 4.12 Adoption rates of good irrigation practices in 2017 and 2019 (sprinkler)

The x-axis shows the applied irrigation volume (l/tree/ha). The y-axis indicates the number of farmers applying a certain volume of water (%).
The sum of the blue full colored bars shows a 53% adoption rate in 2019 (irrigation volume less than 600 l/tree/round).

Currently, farmers apply on average 585 l/tree/round, 689 l/tree/round and 637 l/tree/round for respectively hose, overhead sprinkler and a combination of both methods. The recommended water volumes per tree are respectively 400 l/tree/round, 600 l/tree/round and 500 l/tree/round. These figures (Table 4.4) will be used in the landscape modeling described below.

4.4.2 Intercrops: pepper, avocado and durian

The crop water requirements for alternative intercrops are taken from WASI and summarized in Table 4.5 below.

Table 4.5 Crop water requirements for intercrops

The table is broken down by crop simulation model, i.e. monocrop coffee, intercrop coffee on suitable land and intercrops only (without coffee) on unsuitable (water scarce) land.

Crop models	Trees (#/ha)	Irrigation volume (m^3/ha/y)
Coffee (monocrop)		
Current irrigation	1,110	2,043
Optimal irrigation	1,110	1,515
Coffee (intercrop)		
Suitable land		
Coffee	887	1,211
Pepper	336	134
Avocado	28	34
Durian	28	21
Unsuitable land		
Pepper	1,362	545
Avocado	35	42
Durian	35	26

4.5 Crop modelling

4.5.1 Crop life cycle

Based on literature review and discussion with experts, the crop life cycles for Robusta coffee (*Coffea canephora*), black pepper (*Piper nigrum*), Avocado (*Persea americana*) and Durian (*Durio*) were developed (Figure 4.13 and Table 4.6). The latter three species were recommended by WASI as potential intercrops.

The coffee life cycle starts with 2 zero-production years and subsequently 5 linear production increase years (i.e. from year 3 to 8 productivity linearly increases from 0.5 to 6.0 t/ha). The maximum potential yield is reached in year 8. The stable maximum potential yield phase counts 10 years (years 8 to 17) after which productivity declines linearly to 0.75 t/ha in year 25. Table 4.6 gives on overview of the life cycle stages and maximum potential yields for all four crops.

For the below macro-economic modeling a maximum time horizon of 30 years is applied.

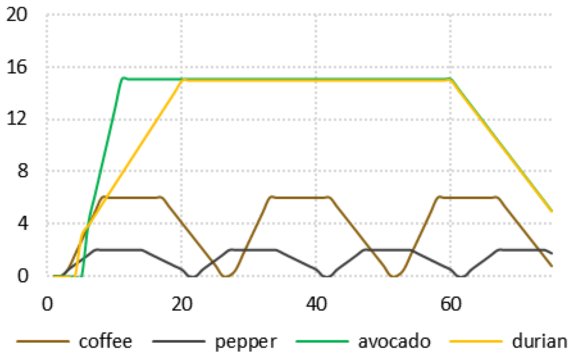


Figure 4.13 Crop life cycle by crop species (t/ha)

The time horizon (x-axis) covers 75 years to allow visualization of the downward trends for avocado and durian after 60 years and the cyclical patterns for coffee and pepper (25 and 20 years respectively).
The y-axis shows the yield per crop species (t/ha).
Each life cycle assumes monocrop farming, applying best agricultural practices to achieve maximum potential yield.

Table 4.6 Crop life cycle stages and maximum potential productivity by crop species

Crop life cycle stages are expressed in years and the maximum potential yield in t/ha

Crop	**Not productive**	**Production increase**	**Stable maximum production**	**Production decrease**	**Total life cycle**	**Maximum potential productivity**
Coffee	2	5	10	8	25	6
Pepper	2	4	8	6	20	2
Avocado	5	5	50	15	75	15
Durian	4	15	41	15	75	15

4.5.2 Optimization of the rejuvenation cycle

To determine the most productive rejuvenation cycle for each crop species, first the respective crop life cycles were constructed (cf. chapter 4.5.1). The simulated production figures (t/ha) were plotted in a matrix form. Columns depict the production years, rows the rejuvenation cycle years (Figure 4.14, top graphs). E.g. if one replants partially in year 5, then a new crop life cycle starts in that production year (cf. row 5 below in the graphs at the top).

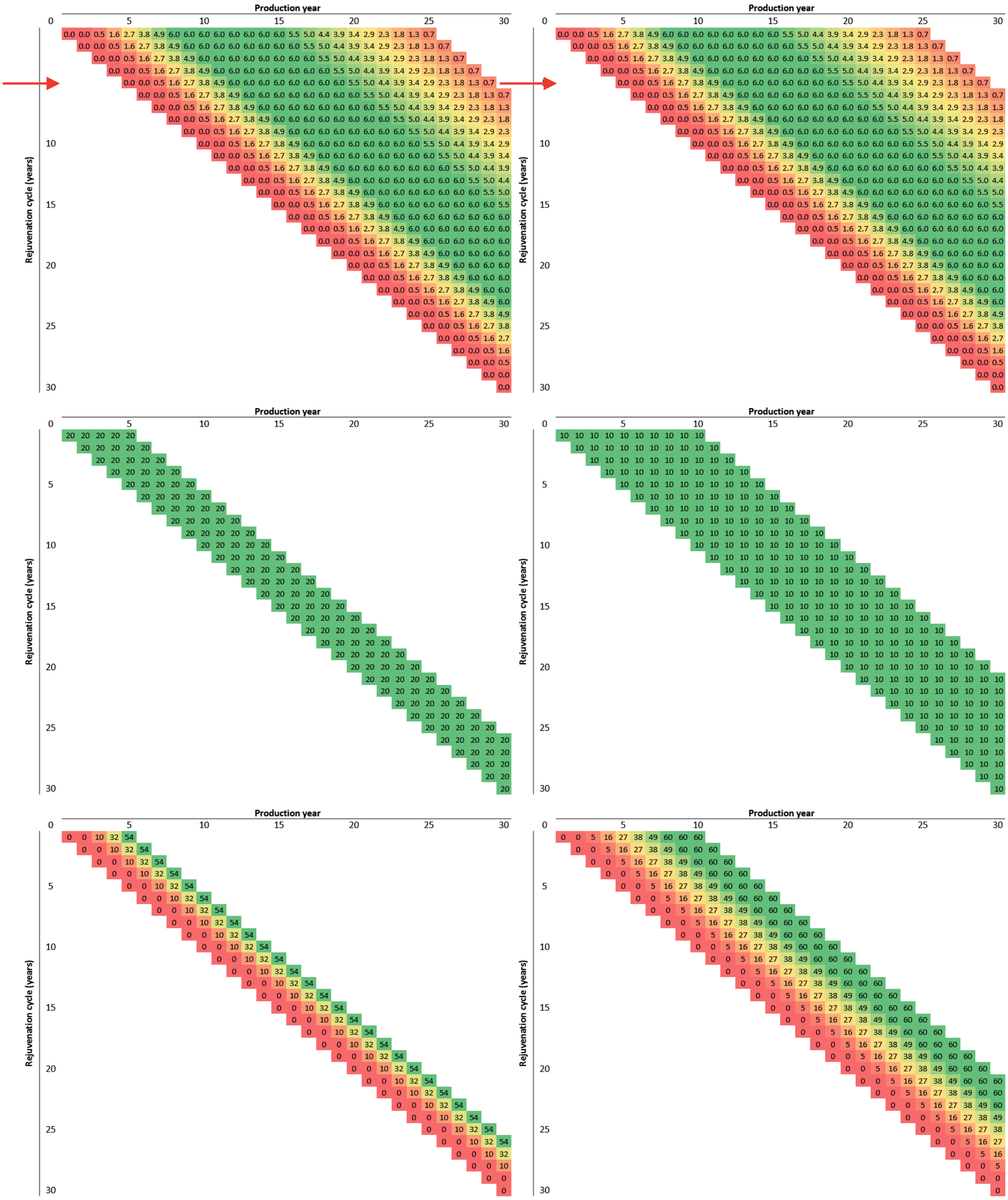


Figure 4.14 Coffee life cycle, rejuvenated area and total production for 5 (left) and 10 (right) years

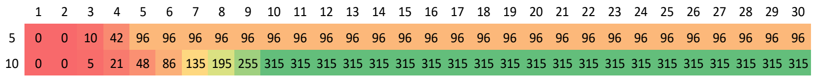
The top graphs show the productivity change over time or the crop life cycle (t/ha)
The middle graphs show examples of rejuvenation schemes; over 5 years at the left and over 10 years at the right (ha)
The bottom graphs depict the total production i.e. the product of the above matrices (t).

In a second step, the crop rejuvenation cycles were developed and plotted in a matrix format (graphs in the middle of Figure 4.14). As above, columns depict the actual production years, while rows are the rejuvenation years. Assume a farm has a total area of 100 ha. In the first case (left middle graph) the total land area is rejuvenated over 5 years (i.e. 20 ha/y). In the second case (right middle graph), rejuvenation is planned over 10 years (i.e. 10 ha/y). Rejuvenation cycle matrices were designed for 1 until 30 years (i.e. 30 matrices in total).

In the third step the crop life cycle matrix is multiplied with each unique rejuvenation cycle matrix, resulting in 30 new total production matrices (Figure 4.14 bottom graphs), where each unique row/column combination represents the specific crop production for a specific rejuvenated area. E.g. column 4/row 1 (bottom left graph) is equal to 32 t (i.e. 1.6 t/ha multiplied by 20 ha).

Subsequently, the totals were calculated for each production year. E.g. in the bottom left graph in Figure 4.14 (rejuvenation cycle of 5 years), the sum of the values in columns 1, 2, 3, 4 and 5 are respectively 0, 0, 10, 42 and 96. In contrast, the sum of the first 5 columns (or production years) for a 10-year rejuvenation cycle, results in 0, 0, 5, 21, 48. Summing the columns for each total production matrix results in 30 1-dimentional matrices (2 are shown as an example in Figure 4.15).

Finally, the average was calculated for each rejuvenation cycle. The one with the highest average over 30 years results the optimum rejuvenation cycle.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
5	0	0	10	42	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96
10	0	0	5	21	48	86	135	195	255	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315

Figure 4.15 Example total production per year and per rejuvenation cycle

Columns indicate production years and rows rejuvenation cycle years. Rows 1 and 2 refer respectively to 5- and 10-year rejuvenation cycles.

The above procedure was repeated for each crop species (4 in total) and run separately for (i) the entire current coffee area, (ii) the suitable coffee areas and (iii) the unsuitable coffee areas.

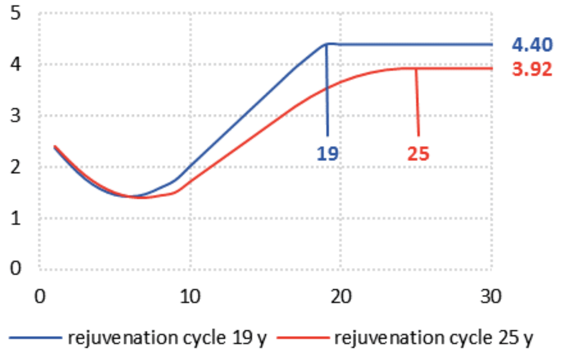


Figure 4.16 Simulation of monocrop coffee production over time for two rejuvenation cycles

The red line simulates monocrop coffee production over time (t/ha) and assumes replanting every 25 years.
The blue line simulates monocrop coffee production over time (t/ha) and assumes replanting every 19 years.

Figure 4.16 shows the total coffee production per year for 2 distinct rejuvenation cycles (19 and 25 years) per hectare. These were chosen as the 19 year-cycle results in the highest average yield (among all 30 scenarios analyzed) and 25 years coincides with the end of the productive lifetime for coffee. It shows that the better option is to rejuvenate earlier as the overall average yield will stabilize at 4.4 t/ha, 12% higher than the stable end yield for a 25-year cycle.

At the landscape level 19 years may be an interesting option to spread required investment costs over a longer time horizon. However, at the macro-level one may want to transition faster if possible. Faster transitioning meaning that larger areas need to be converted on an annual basis.

At the farm level, a farmer would usually try to rejuvenate over a shorter time horizon if financing allows. However, it would be good to keep a 19-year rejuvenation cycle once the farm is fully replanted. This is equivalent to rejuvenating 3-5 % or ~55 trees per hectare annually for monocrop farming. This will guarantee a stable yield over time (beyond 25 years) and allows spreading investments. One can look at this as a depreciation process.

4.5.3 Agricultural land use transformation scenarios

In this report with a focus on agricultural transformation for the Central Highlands, two land use scenarios will be assessed:

1. Coffee monocrop
   This is the business as usual (BaU) scenario where it is assumed that farmers continue growing coffee as a monocrop (i.e. 1,110 trees per ha) in the current coffee areas (~586,000 ha in the Central Highlands; cf. section 4.3). The model assumes that farmers rejuvenate gradually and replace old coffee trees with better varieties (e.g. TRS1, TR4, TR9 and TR11) at a pace of ~5% per year equivalent to a full replacement over 19 years (cf. optimal crop rejuvenation cycle described in chapter 4.5.2). At landscape level a 19-year rejuvenation cycle is equivalent to ~31,000 ha conversion of land use annually.
2. Coffee intercrop
   In this new scenario a distinction in land use destination at landscape level is made based on the aforementioned land suitability analysis (cf. chapter 4.3) which shows that ~532,000 ha is suitable for coffee production, while ~ 32,500 ha faces seasonal water scarcity. Therefore, this new scenario is split into 2 parts:
   a. suitable land units where coffee is grown intercropped with pepper, avocado and durian; and
   b. unsuitable (water scarce) land units where coffee is replaced by an intercropped farming system with pepper, avocado and durian only.

4.5.4 Maximization of gross revenue at farm and landscape level

As described above, the agricultural transformation model aims to diversify agricultural production in order to save water and maximize gross revenues. Gross revenue is calculated by multiplying the annual yield (t/ha) by average annual price (USD/t) per crop species. Average annual crop prices were derived from various sources (Figure 4.17 and Table 4.7).

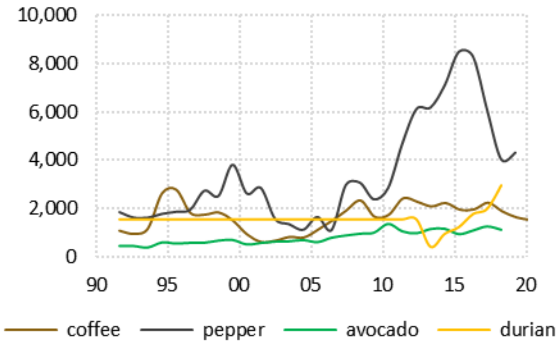


Figure 4.17 Historic annual average crop price

The x-axis depicts calendar years starting in 1990.
Prices in the y-axis are in USD/t.
Sources
Coffee: https://ycharts.com/indicators
Pepper: FAOSTAT Vietnam
Avocado: FAOSTAT (average top 10 countries)
Durian: Own data compilation based on various sources

Table 4.7 Average annual crop price

The average annual crop price (USD/t) was calculated based on data from 1991 to 2018.
Data sources are provided in (Figure 4.17)

Crop	USD/t
Coffee	1,650
Pepper	3,399
Avocado	793
Durian	1,556

To maximize gross revenues[4], the best combination of crops in terms of plants per hectare needs to be identified. Multiple goal linear programming was applied to resolve this problem using Excel Solver software. With this method it is possible to determine the number of plants per crop species per hectare, while maximizing the total gross revenue for all species over a 30-year time horizon. In the process, constraints can be added, e.g. the maximum number of coffee trees may not exceed 1,110 per hectare or coffee production in year 30 must be 20% higher than the production in year 1.

Several iterations were run, starting with few simple constraints and stepwise adding more and more complex constraints. For example, in the first simple scenario, the model only assumes that the number of plants per hectare per species cannot exceed the maximum plant density under monocrop conditions and the sum of the area taken per crop species may not exceed 1 ha (i.e. 10,000 m^2). In this case the model shows that no pepper should be planted, which violates the goal of maximum crop diversification. Therefore, new constraints were added. Table 4.8 shows an overview of all model constraints and the resulting combined number of plants per hectare. The model outputs are different for suitable and unsuitable (water scarce) land units because on the latter no coffee is planted.

Table 4.8 Model boundary conditions and constraints

Area suitable for coffee production

Goal	***Maximize the total gross revenue of an intercropped farming system consisting of coffee, pepper, avocado and durian over a 30-year time horizon***	
Constraints	# coffee trees:	maximum 1,110 trees
	# pepper poles:	maximum 2,500 poles
	# avocado trees:	maximum 154 trees
	# durian trees:	maximum 154 trees
	# avocado trees:	equals # durian trees
	Total coffee production in year 30:	20% higher compared to current coffee production
Results	# coffee trees:	887
	# pepper poles:	336
	# avocado trees:	28
	# durian trees:	28

Area unsuitable for coffee production (water scarce)

Goal	***Maximize the total gross revenue of an intercropped farming system consisting of pepper, avocado and durian only over a 30-year time horizon***	
Constraints	# pepper poles:	maximum 2,500 poles
	# avocado trees:	maximum 154 trees
	# durian trees:	maximum 154 trees
	# avocado trees:	equals # durian trees
	Sum of avocado and durian trees:	equals 70 trees
Results	# coffee trees:	0
	# pepper poles:	1,362
	# avocado trees:	35
	# durian trees:	35

---

[4] Maximum gross revenue in this case, is defined within a framework of boundary conditions, i.e. assuring significant water savings for irrigation, while increasing total coffee production by at least 20% in fully diversified cropping systems.

4.5.5 Calculation of investment costs and Return on Investment

To investigate the investment needs, a budget was constructed over a 20-year time horizon. The most important costs are allocated to farmer training and awareness raising through communication media, establishment of nurseries and production of seedlings as well as personnel and expert expenses (cf. chapter 5.1.4).

To assess the cost and benefits of an investment program, the Return on Investment (RoI) was calculated using Equation 4.1.

Equation 4.1 Return on Investment

$$\mathrm{RoI_i} = \frac{(\mathrm{G_i} - \mathrm{I_i})}{\mathrm{I_i}}$$

RoI = Return on Investment in year i
G = Gross revenue in year i; i.e. sum gross yield per crop species (coffee, pepper, avocado and durian) + cost savings for irrigation labor and energy
I = Investment in year i

4.5.6 Calculation of the profit/loss probability and risk exposure

In order to understand the probability of making an annual loss or profit and the associated value or risk for the intercrop model compared to the current situation, a Monte Carlo simulation was conducted.

At first, the historic prices for each crop were tested for normality using the Shapiro-Wilk test. This showed that the time series deviate significantly from normality. Therefore, a Kernel Density Estimation (KDE) was used to estimate the probability density functions for each historic crop price timeseries. As an example, Figure 4.18 shows the non-normal distribution of historic coffee prices (1991-2020) in a traditional histogram, while Figure 4.19 depicts its estimated probability density function.

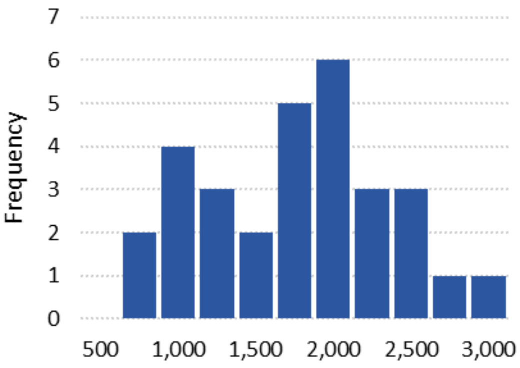


Figure 4.18 Traditional histogram of historic coffee prices (1991-2020)

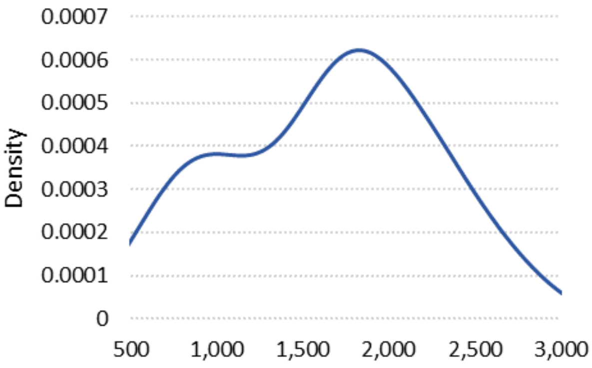


Figure 4.19 Kernel Density Estimation of historic coffee prices (1991-2020)

Subsequently the probability density function was used to generate a set of 1,000 random coffee prices following the trend depicted in Figure 4.19, applying Excel's discrete random number generator. For each year (total=30) and each crop (coffee, pepper, durian and avocado), this process was repeated.

A similar approach was used, to generate 1,000 random crop yields per crop species and per year. In this case a normal distribution was assumed with the modelled yield (cf. chapter 4.5.1 and 4.5.2) per year as average and the standard deviation set equal to 25% of the average yield.

Multiplying prices and yields results in 1,000 random gross income values per year, for BaU in year 1 (i.e. a yield that fluctuates around an average of 2.37; cf. Figure 5.11, year 1) and the intercrop model. Subtracting the gross income of the intercrop model from the current value gives the profit or loss for each simulation run (n=1,000) in each year (n=30). Figure 4.20 shows an example of 5 random trials over 30 years. The Shapiro-Wilk test indicates that profit/loss values are normally distributed in each year. A subsequent frequency analysis, i.e. counting the number of negative (loss) and positive (profit) values, generates the probability of profit or loss within each year and their average annual absolute value. Multiplying the probability with absolute profit/loss value, finally results in a risk value (i.e. exposure to loss or profit).

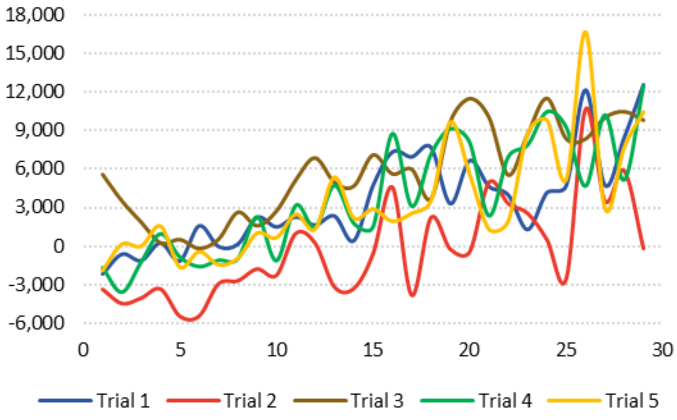


Figure 4.20 Random profit/loss value over time

Each line depicts a random trial out of 1,000 Monte Carlo simulation runs over 30 years.
The profit/loss value is the difference between an intercropped farming system and the current situation (USD/ha)

4.5.7 Carbon sequestration

To understand the effect of crop diversification on climate change mitigation, sequestered carbon was estimated. For Robusta coffee the allometric equation of Guillemot et al. (2018) was applied, while for fruit trees such as avocado and durian, the generic model of Ketterings et al. (2001) was used (Equation 4.2 and Equation 4.3). To convert biomass to carbon a factor 0.5 was used. Raw data on trunk circumference for coffee (n=111) and trunk diameter for avocado and durian (n=35 for each crop type) were obtained from Agri-Logic (2018). To simulate carbon sequestration over time, simple correlations were made between crop age and the trunk circumference for coffee ($R^2 = 0.6178$) and trunk diameter for avocado and durian (respectively $R^2 = 0.7485$ and $R^2 = 0.8032$). The projected crown diameter for coffee linearly increases to 9 m^2 in year 8. Pepper was not included in the analysis because it is not considered to contribute significantly to carbon sequestration.

Equation 4.2 Aboveground biomass for coffee

$$B_{\text{robusta coffee}} = 0.0177 \times C^{1.408} \times PCA^{0.818}$$

B = Aboveground Biomass (kg / tree)
C = Circumference of the trunk at 30 cm (cm)
PCA = Projected Crown Area (m^2)

Equation 4.3 Aboveground biomass for fruit trees

$$B_{\text{fruit tree}}=0.066 \times D^{2.59}$$

B = Aboveground Biomass (kg / tree)
D = Diameter trunk at breast height (cm)

5. Results

5.1 Landscape level

5.1.1 Higher coffee production with fewer trees

Crop production simulation at the landscape level for the BaU scenario (i.e. all current coffee areas in the Central Highlands) shows that the yield in year 1 for monocrop coffee, rejuvenated over 19 years, is about 1.55 million metric ton (Figure 5.1). This is in line with estimated Robusta figures reported for the 2020/2021 crop year (i.e. 28 million 60 kg bags or 1.68 million tons on an estimated area of 620,000 ha, 6% higher than the estimate in this study i.e. 586,000 ha; USDA GAIN, 2021). Under monocrop (BaU) conditions, the total output reduces to a minimum of 950,000 t in year 6 (-39% vs. year 1), then recovers to break even in year 13 (1.67 mio. t) to reach a stable production of ~2.58 mio. t as of year 19. This is 66% higher compared to year 1.

In the second scenario, whereby coffee farms on suitable land are fully intercropped and coffee on water scarce areas is replaced by other crops (a combination of pepper, avocado and durian), total production in the Central Highlands drops to a minimum of 832,000 t in year 7 (-46% versus year 1), then climbs to a break-even in year 16 (1.58 mio. t), reaching stable production in year 19 (1.87 mio. t). This is 20% higher compared to year 1.

In the intercrop scenario, total production for pepper, durian and avocado in the Central Highlands will reach an annual stable maximum of 0.13 mio. ton, 0.92 mio. ton and 1.1 mio. ton respectively in year 25 (Figure 5.2).

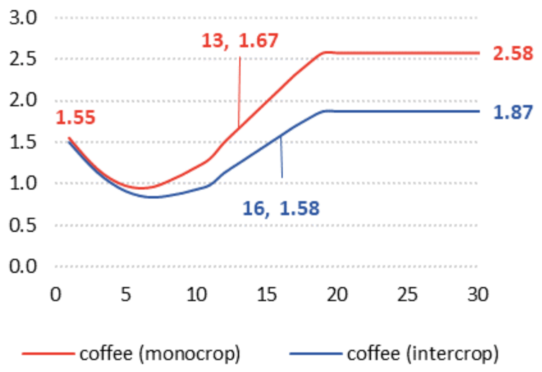


Figure 5.1 Annual coffee production at landscape level

The red line depicts the BaU scenario (monocrop coffee rejuvenated over 19 years) and the blue line shows the fully intercropped model (mio. t/y).

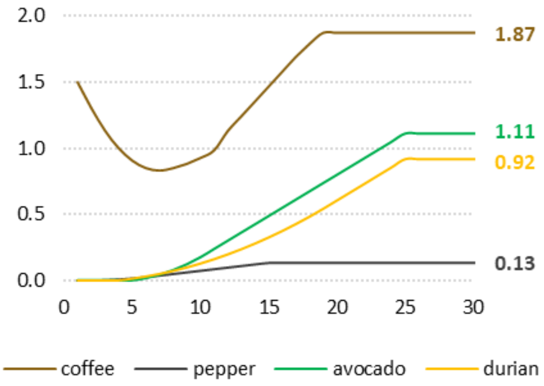
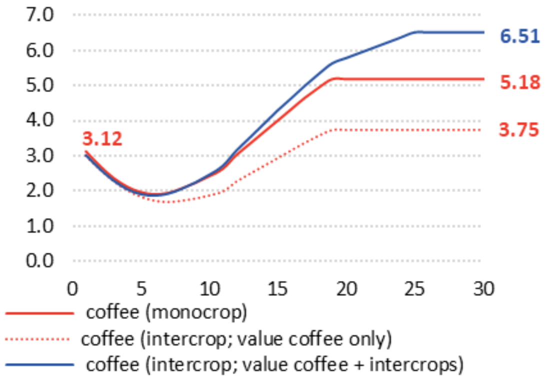


Figure 5.2 Annual production per crop species at landscape level

For each crop species the total annual production for the Central Highlands is shown (mio. t/y).

5.1.2 Higher gross revenue through diversified farming

In terms of gross revenue generation, the BaU scenario at landscape level results in a 66% increase in average annual value, i.e. 5.18 billion USD/y as of year 19 compared to 3.12 billion USD/y in year 1 (Figure 5.3) at an average coffee price of 2,000 USD/t. For the intercrop scenario the value addition as of year 25 is twice year 1 or 26% higher compared to a stable coffee monocrop system. In the intercrop system based on average prices, coffee contributes most to the value generation, followed by durian, avocado and pepper (Figure 5.4).



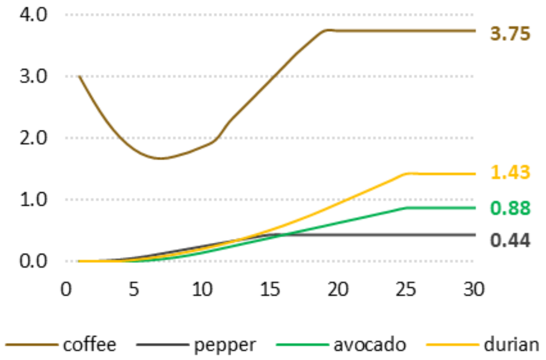


Figure 5.3 Annual gross revenue at landscape level

Figure 5.4 Annual gross revenue by crop species at landscape level

The solid red line depicts the BaU scenario, the dotted red line shows the value for only coffee in an intercropped system and the blue line shows the value for a fully intercropped model (coffee + intercrops). The gross income (billion USD) is calculated based on the average crop price from 2011 until 2020.

The gross income (billion USD) is calculated based on the average crop price from 2011 until 2020.

5.1.3 More coffee and other crops with less water

In the Central Highlands, monocrop coffee under current excessive irrigation conditions consumes about 1.12 billion m^3 water per year (Figure 5.5). If irrigation management is optimized for monocrop coffee about 290 million m^3 of water can be saved (-26%). In the intercropped scenario, water use gradually decreases until year 19 as coffee is gradually taken out on the water scarce land units. In this case 407 million m^3 of water can be saved as of year 19 compared to the BaU (-36%).

Optimization of water use goes hand in hand with cost savings for labor and energy. About 38 million USD can be saved annually or ~ 65 USD/ha/y. Out of the total irrigation cost, 42% goes to labor and 58% to energy (Figure 5.6).

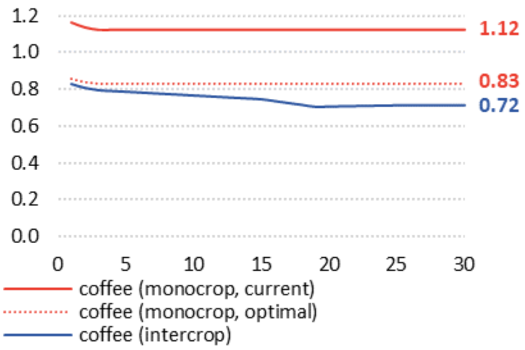


Figure 5.5 Water use per scenario at landscape level

The solid full line depicts the BaU scenario (excessive irrigation), the dotted red line is the BaU for optimized irrigation and the blue line shows the fully intercropped model with optimal irrigation (bil. m^3).

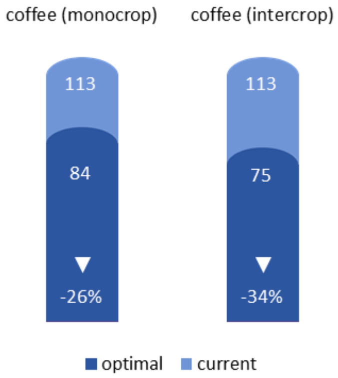


Figure 5.6 Average annual irrigation costs per scenario at landscape level

The total irrigation cost is the sum of energy cost for pumping (58%) and labor (42%), expressed in mio. USD.

5.1.4 High return on investment

Agricultural land use transformation comes at a cost. Table 5.1 presents the total investment costs for a 20-year program of ~638 million USD. This is equivalent to ~50-60 USD per farmer per year (assuming 1 ha per farming family). It is recommended to implement a large-scale training program for farmers on good agricultural practices for all crops and financial literacy in combination with regular awareness raising through simple and short TV spots explaining the socio-economic and environmental benefits of diversified farming.

The agricultural education program ideally starts off with a thorough training of local trainers (government extension officers as well as agronomists of private traders and end-buyers) by professional agricultural extension experts. It is assumed to train 470 extension officers and agronomists (three 4-day trainings per year) on sustainable diversified farm management (i.e. coffee + a choice of intercrops).

Table 5.1 Investment projection over 20 years for the Central Highlands (USD)

The investment foresees per province 1 program manager and 2 agronomists.

Investments	Total Cost
Training program	**67,900,000**
Training of Trainers	1,400,000
Farmer Field Schools	5,000,000
Farmer Coaching Visit	61,500,000
Seedlings	**449,100,000**
Coffee	209,200,000
Pepper	34,900,000
Avocado	56,700,000
Durian	146,500,000
Establishment nurseries	1,800,000
Awareness raising campaign	**10,500,000**
TV spots	10,500,000
Personnel	**81,300,000**
FFS trainers	9,500,000
FCV trainers	64,400,000
Agronomists	4,200,000
Program manager	3,200,000
Other	**28,700,000**
Transport	28,700,000
Grand total	**637,500,000**

Subsequently, the extension officers provide farmer training in traditional Farmer Field Schools (FFS) for groups of 25 farmers (10 FFS per beneficiary), and additionally through one-on-one Farmer Coaching Visits (FCV; 10 per beneficiary). Through FCVs, the trainers reach out to individual farms where they appraise the farm management conditions in the field and provide ad hoc advice. This approach is envisaged to be more impactful. However, this more intensive approach is also costlier.

Table 5.2 Investment projection over 20 years per province (USD)

Province	Coffee Area	Investment
Kon Tum	3%	19,297,709
Gia Lai	18%	112,386,664
Dak Lak	36%	228,224,451
Dak Nong	16%	105,268,117
Lam Dong	27%	172,323,058
Grand total	**100%**	**637,500,000**

In parallel, it is recommended to invest in professional nurseries to produce coffee, pepper, avocado and durian seedlings. The investment costs include the cost for seedlings either to be paid by farmers at market price or subsidized by the government and/or the private sector. Table 5.2 shows the estimated investment costs broken down per province based on the respective coffee areas.

Figure 5.7 shows the cumulative annual program investment versus the cumulative added value (difference between monocrop coffee and fully diversified farming) at the landscape level for a 19-year rejuvenation cycle. The added value significantly offsets the investment costs. The ROI breaks even in year 14 (i.e. ROI = 0.31) and reaches ~1 in year 15, i.e. for every USD spent 1 USD is earned. However, if one aims to transform agriculture in the Central Highlands over a shorter time span, e.g. 10 years (Figure 5.8), the ROI will only break even after 28 years. This is because larger areas will be rejuvenated annually (~56,000 ha/y), resulting in high gross revenue losses combined with the fact that it takes 7-10 years for coffee and the intercrops to reach maximum potential productivity. Moreover, investment costs will be significantly higher on a year by year basis.

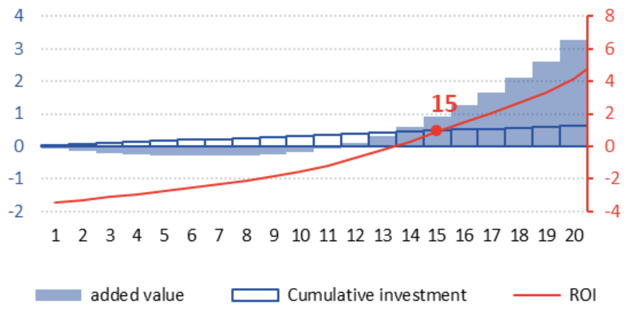


Figure 5.7 Cumulative investment over 20 years and cumulative added value vs. BaU at landscape level

Added value (bil. USD) is the sum of annual irrigation savings for coffee (labor and energy) plus the gains in gross revenue because of diversification, the use of higher yielding plant varieties and application of good agricultural practices. The red line depicts the annual ROI; the red dot on this line indicates the year where the ROI exceeds 1.

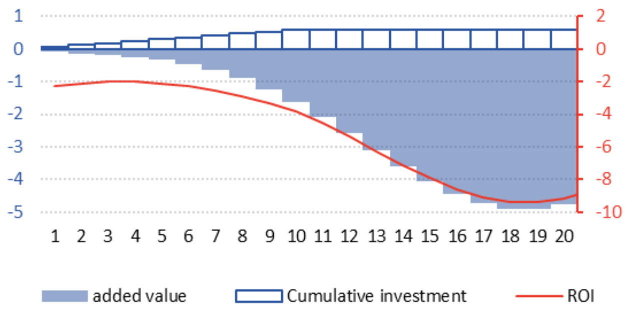


Figure 5.8 Cumulative investment over 10 years and cumulative added value vs. BaU at landscape level

Added value (bil. USD) is the sum of annual irrigation savings for coffee (labor and energy) plus the gains in gross revenue because of diversification, the use of higher yielding plant varieties and application of good agricultural practices. The red line depicts the annual ROI.

5.1.5 Carbon sequestration potential for the Central Highlands

Based on allometric equations, the potential for carbon sequestration was calculated for BaU (monocrop coffee) and for a fully intercropped farming system. The simulation assumes for both scenarios that the current (i.e. simulation year 1) Central Highlands' wide coffee tree stock has an average age of 15 years. This is equivalent to a carbon stock of 5.7 mio. tons (Figure 5.9). For monocropping, the carbon stock gradually reduces and stabilizes at 3.8 mio tons. This trend may look odd but can be explained by the fact that trees will continuously be rejuvenated following a 19-year crop cycle to maximize productivity. In other words, the average age of the tree stock will stabilize at 10 years (i.e. at any given time there will be trees in a range of 1 to 19 years in the same field).

For the intercrop model a similar downward trend is observed, but from year 19 onwards, additional carbon sequestered by avocado and durian trees adds to the equation, resulting in a total carbon stock of 6.9 mio tons at landscape level or 21% higher compared to the current situation (year 1). In decreasing order, coffee is the main contributor to the carbon stock, followed by durian and then avocado (Figure 5.10). Note that in absolute terms if either of the three crops are planted as a monocrop, then durian has the highest carbon capturing potential, followed by avocado and then coffee (Figure 5.23 in chapter 0).

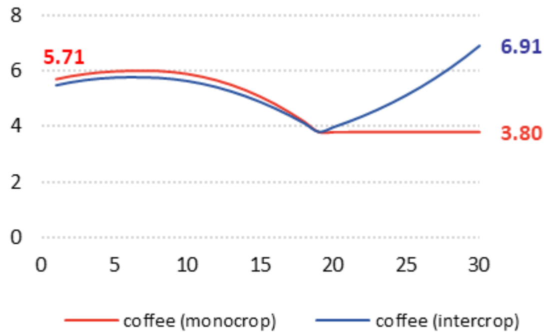


Figure 5.9 Carbon sequestration over time for monocrop and intercropped coffee (landscape)

The x-axis shows the timeline (y) and the y-axis the carbon amount sequestered (mio. t).
The red line is coffee only (1,110 trees/ha) and the blue line is the sum of coffee, avocado and durian (respectively 887, 28 and 28 trees/ha).
An average age of 15 years is assumed for coffee trees in year 1.

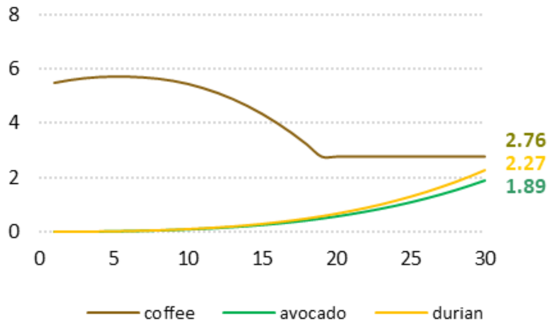


Figure 5.10 Carbon sequestration over time broken down by crop species (landscape)

The x-axis shows the timeline (y) and the y-axis the carbon amount sequestered (mio. t).
The number of trees per hectare for coffee, avocado and durian are respectively 887, 28 and 28.
An average age of 15 years is assumed for coffee trees in year 1.

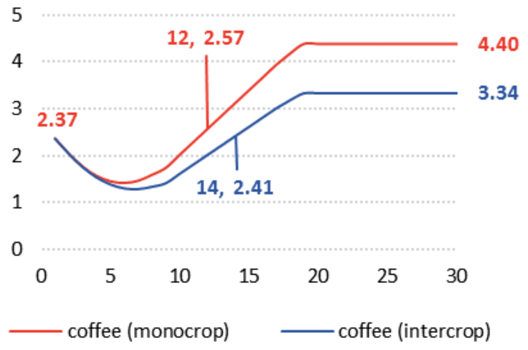
5.2 *Farm level*

5.2.1 Higher coffee production with fewer trees

The crop production simulation (Figure 5.11) shows that the farm level yield in year 1 for BaU (monocrop coffee) is ~2.37 t/ha. This is in line with a recent ICO report (2019), mentioning that the average national coffee production stands at 2.3 t/ha. Under BaU conditions, farm output declines to a minimum of 1.41 t/ha in year 6 (-40% vs. year 1) and then recovers to break-even in year 12 (2.57 t/ha), to reach stable production in year 19 (4.4 t/ha). This is 86% higher compared to year 1.

In the new agricultural transformation model, it is assumed that farmers plant only 887 coffee trees (high yielding variety with a maximum potential productivity of 6 t/ha), intercropped with pepper, avocado and durian, compared to the traditional 1,110 coffee trees mono-cropped per hectare (-20%). In this scenario, the coffee yield drops to 1.29 t/ha in year 7 (-46% versus year 1), then climbs to break even in year 14 (2.41 t/ha) to reach stable production in year 19 (3.34 t/ha). This is 41% higher compared to year 1.

Figure 5.11 shows that it takes more time for the intercrop system to reach the same coffee yield per hectare (compared to BaU), since there are 20% less coffee trees. The decline in yield and consequent income loss are partially compensated by the upcoming production of the intercrops (cf. chapter 5.2.2).



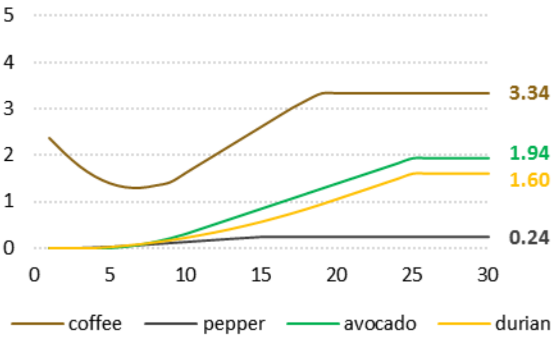


Figure 5.11 Annual coffee production at farm level

The red line depicts the BaU scenario (monocrop coffee rejuvenated over 19 years) and the blue line shows the fully intercropped model (t/ha).

Figure 5.12 Annual production per crop species at farm level

For each crop species the total annual production per farm is shown (t/ha).

5.2.2 Higher gross farm revenue through diversified farming

Figure 5.13 shows that intercropped coffee farming will result in a higher gross revenue (based on average crop prices) in the long run. While it takes 14 years for coffee production to get back to the year 1 level (cf. section 5.2.1), the diversified farming system breaks even in year 11 in terms of gross revenues (4,278 USD/ha compared to 3,909 USD/ha in BaU year 1).

Over a 30-year time horizon, a farmer's average annual gross income could theoretically increase from ~3,900 USD/ha (monocrop coffee in year 1) to ~7,300 USD/ha if the farmer decides to continue with monocrop coffee and gradually replaces the tree stock with new higher yielding varieties. In case one converts to intercropping, the average annual gross revenue could go up to ~10,300 USD/ha.

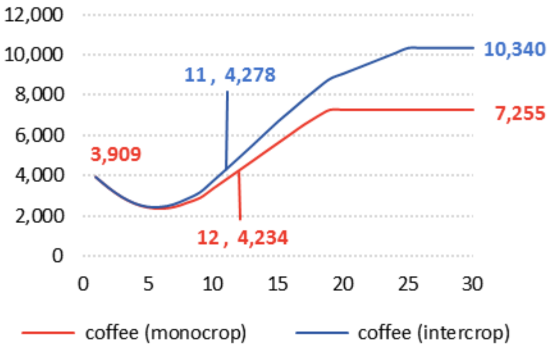


Figure 5.13 Annual gross farm income

The red line depicts the monocrop coffee scenario (BaU), the blue line shows the fully intercropped model. The gross income (USD/ha) is calculated based on the average annual crop price from 1991 until 2018.

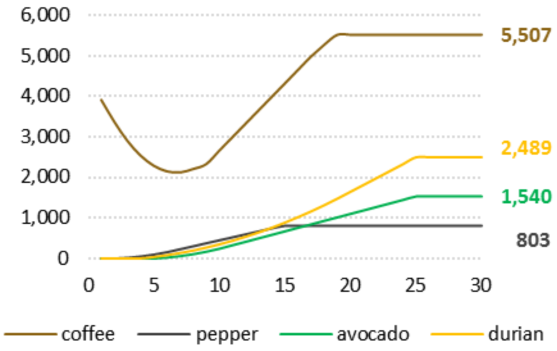


Figure 5.14 Annual gross farm income by crop species

The annual gross income is broken down per crop. The gross income (USD/ha) is calculated based on the average crop price from 1991 until 2018.

5.2.3 Reduced income risks

To estimate farm income streams, a what-if gross revenue simulation was run with historic crop prices (instead of 30-year average prices) for the monocrop coffee and intercrop models respectively. It shows that gross revenue during the coffee crisis years (2001-2003) would have been ~60% higher if the farms were intercropped (2,211 USD/ha vs. 1,390 USD/ha). In more recent years (2017-2019) a downward trend in annual coffee prices is observed. The gross revenue simulation shows, however, that income from monocrop coffee would have steadily declined, while for the intercropped scenario income would have increased (cf. grey masked area at the right in Figure 5.15).

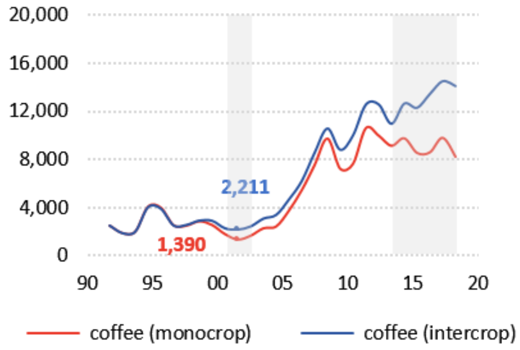


Figure 5.15 Annual gross farm income based on historic crop price

The red line depicts the BaU, the blue line shows the fully intercropped model (USD/ha).
This model assumes historic prices for all crops from 1991 till 2018.
The x-axis depicts calendar years from 1990 to 2020.

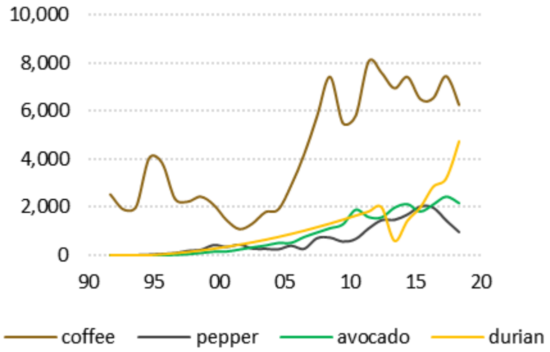


Figure 5.16 Annual gross farm income by crop species based on historic crop price

The annual gross income is broken down per crop (USD/ha).
This graph projects the new agricultural transformation model on historical prices.
The x-axis depicts calendar years from 1990 to 2020.

Besides risk spreading in terms of crop price volatility, the intercrop scenario spreads income streams over time. Figure 5.17 shows the harvest time of the crops studied in this paper.

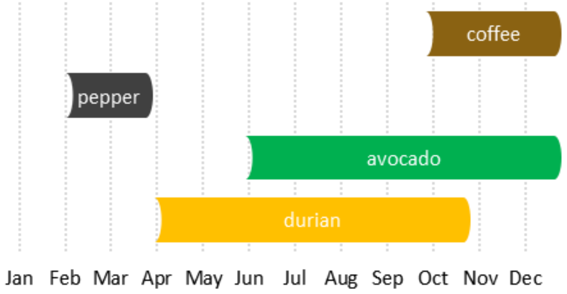


Figure 5.17 Harvest period per crop species

5.2.4 High return on Investment

Comparison of monocrop coffee farming (year 1) with intercropped coffee farming at the individual farm level, whereby it is assumed that the farmers cover the cost for training and purchase of seedlings to rejuvenate and diversify the farm (i.e. investment), shows that for coffee in a monocrop system, the ROI turns positive in year 18 (ROI = 1.21). The added value is the annual gross revenue compared to the gross revenue in starting year 1, i.e. ~3,900 USD/ha (cf. Figure 5.13 in chapter 5.2.2). Figure 5.18 shows that the farmers will accrue losses during the first 17 years, become profitable in year 18, realizing an accumulated added value of ~9,000 USD/ha in year 20.

In case of intercropping, farmers will accumulate losses in the first 15 years, turn profitable in year 16 (ROI = 2.0), earning an accumulated added value of ~22,000 USD/ha in year 20.

The annual average farm investment is estimated at ~60 USD/ha, summing to a total cumulative value of ~1,200 USD/ha over 20 years.

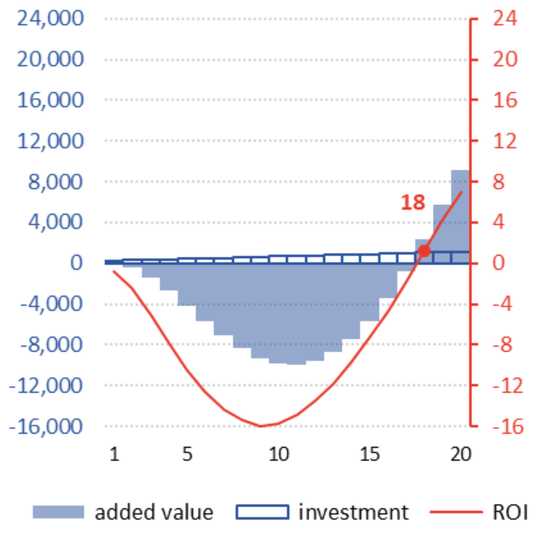


Figure 5.18 Cumulative investment and cumulative added value at farm level for monocrop coffee

The added value (USD/ha) is the sum of annual irrigation savings for coffee (labor and energy) plus the gross revenue compared to year 1 (current situation). The red line depicts the annual return on investment; the red dot on this line indicates the year where the ROI exceeds one.

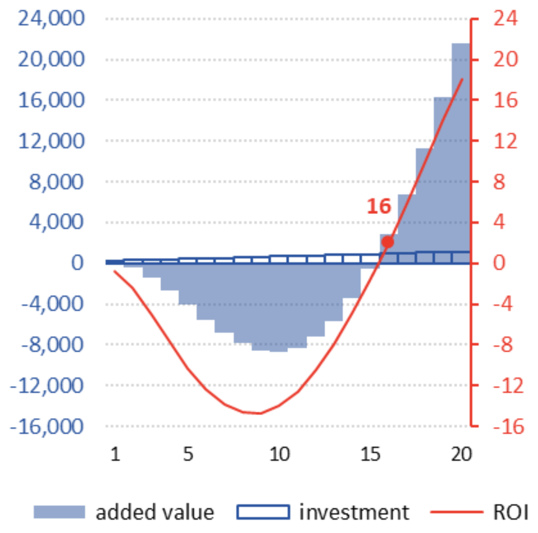


Figure 5.19 Cumulative investment and cumulative added value at farm level for intercropped coffee

The added value (USD/ha) is the sum of annual irrigation savings for coffee (labor and energy) plus the gross revenue compared to year 1 (current situation). The red line depicts the annual return on investment; the red dot on this line indicates the year where the ROI exceeds one.

5.2.5 Initial high financial risk exposure

Applying Monte Carlo simulation, Figure 5.20 shows a summary of the financial risk farmers may face if they decide to transform their farms from coffee monocrop to a fully intercropped system with pepper, avocado and durian. It is obvious that the likelihood of loss is over 50% for the first 10 years, with a peak of ~80% deficit risk in year 5. From year 14 on the probability to make profits is over 80% and the risk of loss becomes negligible (p<10%) as of year 17.

The total average loss value over the first 13 years (probability of loss >20%) is estimated at ~25,000 USD/ha, while exposure to make loss (i.e. average loss times its probability) over the same time period is valued at ~15,000 USD/ha. This loss is fully compensated for by the profits made from year 14 to 19 (6 years), in other words the break-even point is reached after 18 years.

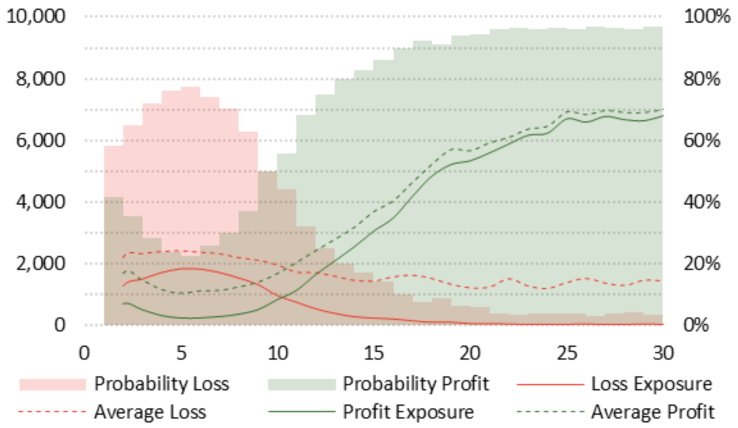


Figure 5.20 Loss/profit probability and value and risk exposure at farm level over time

The probability of loss/profit in gross revenue is shown in the red and green bars (%).
The absolute average loss/profit is depicted by the dashed lines (USD/ha).
The exposure to loss/profit is represented by the full lines (USD/ha)

5.2.6 Increased carbon sequestration

Figure 5.21 shows carbon sequestration trends for monocrop coffee and fully diversified farming as described in the landscape simulation above (cf. chapter 5.1.5). The carbon sequestration for intercropping is almost double in year 30 (12.4 t/ha vs. 6.5 t/ha).

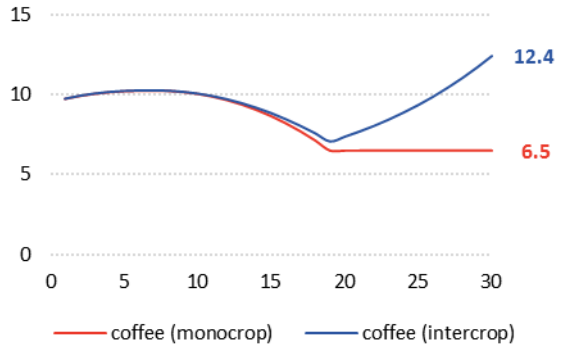


Figure 5.21 Total carbon sequestration for monocrop and intercropped coffee over time

The x-axis shows the timeline (y) and the y-axis the carbon amount sequestered (t/ha).
The red line is coffee only (1,110 trees/ha) and the blue line is the sum of coffee, avocado and durian (respectively 887, 28 and 28 trees/ha).
An average age of 15 years is assumed for coffee trees in year 1.

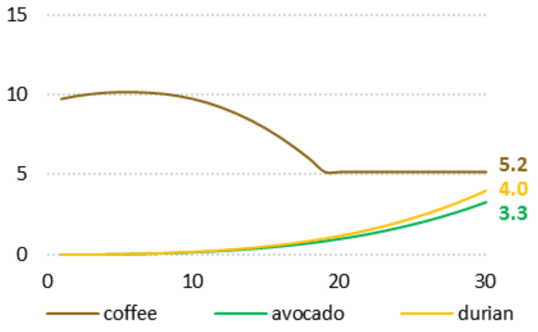


Figure 5.22 Carbon sequestration for intercrop systems over time broken down by crop species

The x-axis shows the timeline (y) and the y-axis the carbon amount sequestered (t/ha).
The number of trees per hectare for coffee, avocado and durian are respectively 887, 28 and 28.
An average age of 15 years is assumed for coffee trees in year 1.

Figure 5.23 shows carbon sequestration over time assuming monocrop farming (without rejuvenation of coffee trees after 19 years). For a mature coffee plantation of 15 years, ~10 tons carbon is captured per ha. This is in line with Kuit et al. (2019) who report 40 metric tons CO_2 per ha for mature monocrop Robusta coffee (i.e. equivalent to ~11 t carbon per ha). Van et al. (2018) report an average carbon stock for coffee in the range of 9.4 to 13.2 t/ha in the Central Highlands.

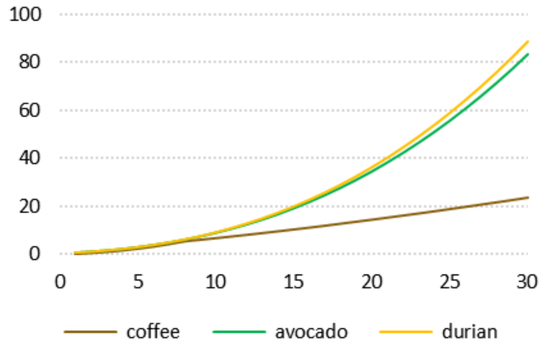


Figure 5.23 Carbon sequestration for monocrop systems over time broken down by crop species

The x-axis shows the timeline (y) and the y-axis the carbon sequestered (t/ha).
The number of trees per hectare for coffee, avocado and durian are respectively 1,110, 240 and 210.
Complete new planting of all crop species is assumed in year 1 and all trees on the farm have the same age in any given year.

6. Summary per province

Table 6.1 provides an overview of the main findings in this report broken down by province. It aims to provide concrete summarized information for decentralized planning and decision making towards agricultural transformation in the Central Highlands.

Table 6.1 Overview main findings by province

Potential production figures refer to values after 25 years.
The investment and total added value are accumulated figures over a 20-years' time horizon.
The annual added value is the expected gross revenue increase compared to the current situation as of year 20 onwards.
Carbon sequestration refers to the total potential amount of carbon sequestered after 30 years.

	Unit	Kon Tum	Gia Lai	Dak Lak	Dak Nong	Lam Dong	Total
Coffee area							
Suitable	ha	16,141	92,418	179,311	93,100	150,918	531,888
Water scarce	ha	214	4,915	24,904	1,718	739	32,491
Not suitable	ha	221	5,847	6,732	1,740	7,284	21,823
Total	ha	16,576	103,180	210,948	96,557	158,941	586,202
Total	%	3%	18%	36%	16%	27%	100%
Potential production							
Coffee	mio. t/y	0.05	0.33	0.67	0.31	0.51	1.87
Pepper	mio. t/y	0.00	0.02	0.05	0.02	0.04	0.13
Avocado	mio. t/y	0.03	0.20	0.40	0.18	0.30	1.11
Durian	mio. t/y	0.03	0.16	0.33	0.15	0.25	0.92
Financials							
Investment	mio. USD	19	112	228	105	172	637
Total added value	mio. USD	264	1,642	3,358	1,537	2,530	9,331
Annual added value	mio. USD/y	87	543	1,111	508	837	3,087
Environment							
Water saving	mio. m^3/y	12	72	146	67	110	407
Energy & labor saving	mio. USD/y	1	7	14	6	10	38
Carbon sequestration	mio. t	0.20	1.22	2.49	1.14	1.87	6.91

7. Conclusions and recommendations

7.1 Economic gains – production and gross revenue

a. Transformation of monocrop coffee farming into diversified production systems does not put Vietnam's overall Robusta coffee production at risk. Reducing the current coffee tree stand by 20% and replacing old coffee trees with new high yielding varieties (e.g. TRS1, TR4, TR9 and TR11) results in a net production increase of 20%. Current production stands at ~1.55 mio. t gbe per year, while stable potential production is estimated at 1.87 mio. t gbe per year as of year 19 onwards.

b. Production of selected intercrops, i.e. pepper, avocado and durian, will reach respectively 0.13 mio. t/y, 1.11 mio. t/y and 0.92 mio. t/y as of year 25 onwards. It should be noted that this is not necessarily all new production. Most likely the above-mentioned intercrops overlap to a certain extent with current production areas. Nevertheless, it remains to be seen whether the market can absorb the production of the suggested intercrops. Some market reports mention:

   Pepper: The global black pepper market is expected to grow in value[5] at 5.5% per year from 2021 to 2028. The market is driven by increased spending on food products and increased disposable income in developing countries. Black pepper is also gaining grounds as an effective and natural preservative in food products.

   Driven by increasing demand for pepper worldwide, the market is expected to continue an upward consumption trend[6]. Market performance is forecast to decelerate, expanding with an anticipated 1.2% annually for a seven-year period from 2018 to 2025, which is projected to bring the market volume to 840 kt by the end of 2025.

   Avocado: The global avocado market is expected to grow in value at 5.7% annually until 2025 mainly driven by health trends[7].

   Durian: The global fresh durian market is projected to grow at 10.6% annually[8] between 2021 and 2026. Rising awareness about health benefits of durian, including anti-oxidant, anti-aging, anti-depressant, cancer prevention and maintenance of blood sugar levels, has been fueling the demand for the product across the world.

c. At the farm level, increased coffee production (average yield increases from 2.37 t/ha to 3.34 t/ha) and additional intercrop production would generate significantly higher gross revenues (+43%). From year 25 onwards, monocrop coffee is estimated to generate on average ~7,255 USD/ha/y, while diversified farming would bring about ~10,340 USD/ha/y (under constant prices over 30 years).

d. Transformation into diversified farming will likely lead to losses valued at ~25,000 USD/ha over the first 13 years. The exposure to make loss (i.e. average loss times its probability) over the same time period is valued at ~15,000 USD/ha. This loss is fully compensated for by the profits made from year 14 to 19 (6 years), in other words the break-even point is reached after 18 years.

e. Transformation to intercropped farming systems requires time and resources. The RoI analysis at landscape level shows that quick conversion towards diversity over a 10-year horizon will lead to losses and only break even in year 28, while a more gradual transformation, following the 19-year crop life cycle of coffee, would turn the RoI positive in year 15.

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[5] https://www.globenewswire.com/en/news-release/2021/11/17/2335973/0/en/Global-Black-Pepper-Market-Is-Expected-to-Reach-USD-5990-65-million-by-2028-Fior-Markets.html

[6] https://www.globaltrademag.com/global-pepper-market-is-expected-to-reach-840k-tonnes-by-2025/

[7] https://www.globenewswire.com/en/news-release/2020/12/02/2138112/28124/en/Global-Avocado-Market-Report-2020-Market-is-Forecast-to-Reach-US-17-905-Billion-by-2025-Increasing-from-US-12-824-Billion-in-2019.html

[8] https://www.mordorintelligence.com/industry-reports/fresh-durian-market

7.2 Environmental gains – water saving and climate change mitigation

a. Transformation of monocrop coffee production to a diversified crop production model comes with considerable water saving. Monocrop coffee under current excessive irrigation conditions (BaU) consumes about 1.12 billion m^3 water per year in the Central Highlands. If all farmers were to optimize irrigation volumes in this scenario, ~290 million m^3 of water can be saved (-26%).
b. For fully diversified farming on suitable land units (coffee, pepper, avocado and durian) and only fruit trees and pepper on water scarce land units, the total water requirement is estimated at ~720 million m^3 per year in the Central Highlands. In this case 407 million m^3 of water can be saved as of year 19 compared to the BaU (-36%).
c. Optimization of water use goes hand in hand with cost savings for labor and energy. About 38 million USD can be saved annually. Out of the total irrigation cost, 42% goes to labor and 58% to energy.
d. Compared to monocrop coffee production, fully diversified farming returns carbon sequestration gains in the order of 82%. Carbon capturing for monocrop coffee will reach 3.80 mio. tons at landscape level in year 30. For intercropped farming systems this will increase to 6.91 mio. tons at the landscape level.

7.3 Intervention strategy – costs and return on investment

a. To realize this agricultural transformation, it is recommended to implement a large-scale training program for government extension officers, private sector agronomists and farmers in combination with regular awareness raising through simple and short TV spots explaining the socio-economic and environmental benefits of diversified farming. In parallel, it is recommended to invest in professional, accredited nurseries to produce coffee, pepper, avocado and durian seedlings.
b. The investment projection for such a long-term program is estimated at ~638 million USD over 20 years. While this figure may look high, it is equivalent to only ~60 USD per farming household per year (assuming 1 ha per farming family) or ~1,200 USD per ha over 20 years.
c. While the investment costs per farmer may be relatively low, agricultural transformation will come with losses compared to the current situation. Only after 18 years farmers would generate a net benefit.

7.4 Recommendations

a. Previous projects learned that adoption of optimal (lower) irrigation application practices takes time despite the fact that coffee yield and product quality are not affected. Therefore, it will be key to translate the proposed intercropping model into a simple concrete business case for communication purpose, clearly emphasizing the direct socio-economic farm benefits. This will likely be more appealing for farmers to change their mindset than messaging water saving for the sake of downstream user benefits.
b. This study showed that for a given coffee life cycle of 25 years, the optimal rejuvenation cycle is 19 years. Currently, farmers typically rejuvenate their farm only after 20-30 years at once or say 50% at a time, based on cash in hand. The better strategy would be to depreciate the farm each year, i.e. rejuvenate each year 3-5% of the worst performing trees in order to maintain a long-term stable yield, hence spreading investment costs over time.
c. In this analysis, 3 alternative intercrops were selected based on research by WASI. The results show that the total production for pepper, avocado and durian could possibly reach an annual output of 0.13 mio. t/y, 1.11 mio. t/y and 0.92 mio. t/y respectively after 25 years. While beyond the scope of this study, it would be important to understand the extent of current production areas for these crops (mono- and intercrop) and resulting actual production in Vietnam. This should be compared with domestic and global supply/demand forecasts in order to quantify if and how much more produce of each crop the market could still absorb in the years to come, avoiding market saturation and inherent price collapse. Further, it might be worth to look at additional intercrops such as macadamia, cashew, passion fruit, vanilla, etc.
d. A total investment of ~638 million USD would be needed over 20 years. However, it requires further stakeholder consultation and discussion with respective government bodies, private sector players (traders, roasters, retail, coffee shops, etc.) and not at least farmers as to how best share costs throughout the supply chain to effectively materialize the suggested agricultural transformation. E.g. currently Vietnam has a fine network of government extension services from the national level, over the provinces, down to the districts and communes. It would be critical to understand the financing gap between current extension expenses broken down per sector (e.g. coffee, fruits and vegetable, rice, livestock) and the required budget to implement the program suggested above. Another observation is that the investment cost for training and acquisition of seedlings (~50-60 USD/farmer/y) is relatively low compared to anticipated gross farm income if spread over time. Therefore, one may consider a farmer-pay-for-service-and-inputs financing model, rather than going for grants, subsidies or government bank loans. A third reflection for further discussion, refers to the payment of premium prices for so-called sustainable mainstream coffee. The roasting and retail industry used certification over the last 20 years to promote and communicate sustainable coffee production at very high cost (premium farm gate price, volume-based commission to the certification bodies and payment for audits, let alone additional logistic cost to separate coffee to keep it traceable to origin) and questionable impact at the farm level. Therefore, it may be worth rethinking the sector’s approach to support sustainable development e.g. by paying into a transparently managed agricultural transformation fund, based on respective coffee volumes sourced at origin.

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