Transforming coffee and water use in the Central Highlands of Vietnam: case study from Dak Lak Province

Dr. Dave A. D'haeze

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1 Abbreviations, Acronyms, Units and Currency

1.1 Abbreviations and Acronyms

BaU	Business as Usual
BRIDGE	Building River Dialogue and Governance
gbe	green bean equivalent
ha	hectare
IUCN	International Union for Conservation of Nature and Natural Resources
NIAPP	National Institute for Planning and Projection
ROI	Return on Investment
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 23,403 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 (particularly Dak Lak Province), 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 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.

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.

Building on the 2019 assessment, the objective of this assignment is to prepare a BRIDGE strategy to directly engage businesses and national and provincial governments in a process to transition coffee production out of coffee monocultures into diverse, higher value, and water saving diversified farming. BRIDGE's role in this transition is intended to be catalytic.

In particular, in this report:

a. The 2019 cost/benefit of a transition towards diversified coffee farming in Dak Lak Province will be revised.
b. The analysis will be expanded to include all five major coffee growing areas in the Central Highlands (covering Dak Nong, Dak Lak, Gia Lai, and Kon Tum Provinces).
c. The results of the expanded analysis will be discussed with important coffee buyers to assess their interest in providing technical and financial support for such a transition.

This analysis differs from the initial rapid assessment paper in the following aspects:

a. In this report the geographic boundary is Dak Lak instead of the 2S river basin. 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 to assess farm income and investment needs at the individual level.
d. This report includes a return on investment 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. Last but not least, this 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 third 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. 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 inhabitants (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 an economically viable livelihood activity, water for irrigation is a pre-condition to achieve yields that average 2.3 Mt 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). In the same year, about 70% of the cultivation areas, which are rainfed or covered by small irrigation systems, 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 that period, smallholder coffee farmers tend to irrigate up to 2 times more than the official recommendation by MARD. 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 level and farm level analysis for transforming coffee monocrop into diversified farming systems.

4 Materials and Methods

4.1 Current land use and land suitability for Robusta Coffee

The current coffee area in Dak Lak was estimated based on SPOT satellite imagery (NIAPP, 2015). This map was overlain with the physical land suitability map1 (NIAPP & KUL, 2002) and the water scarcity map (CHYN, 2015) to identify suitable and unsuitable land units in terms of water scarcity, soil and topographic conditions (Figure 4.1).

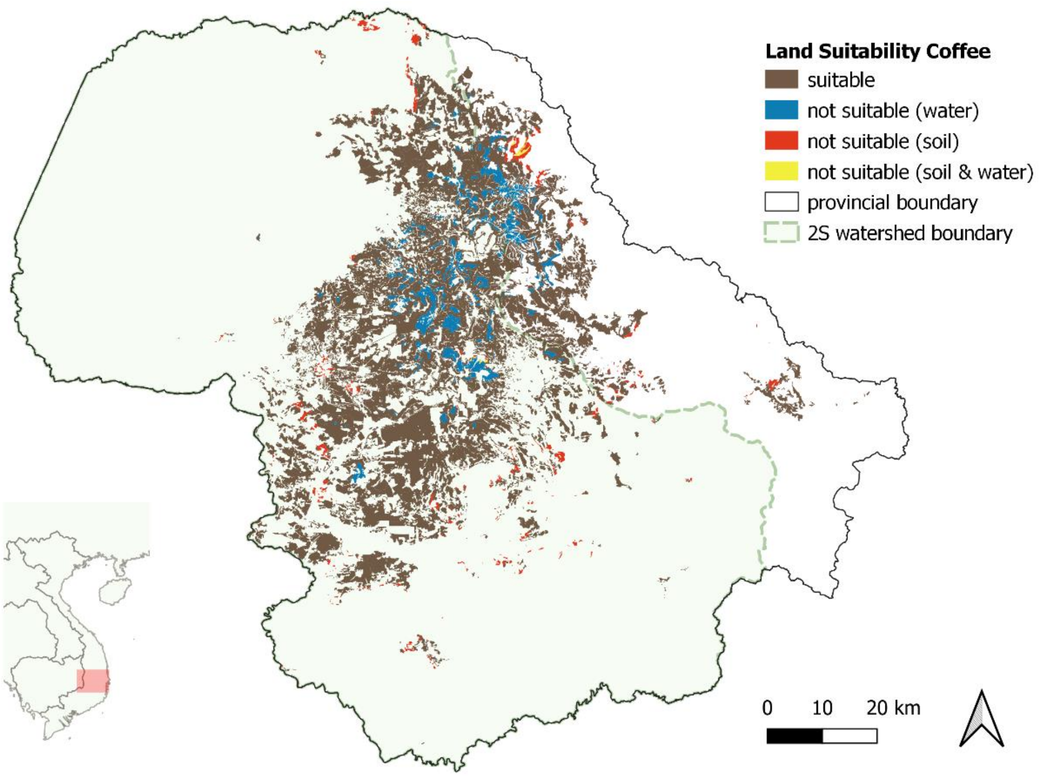


Figure 4.1 Land suitability for coffee production

The map shows the actual land use for coffee in Dak Lak province in 2015.

The colored overlay indicates land suitability for coffee in terms of water scarcity, soil and topographic conditions.

[1] 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.

Table 4.1 Land suitability for coffee production

Land suitability	Dak Lak province		2S Watershed Dak Lak	
	ha	%	ha	%
suitable	188,190	89.0	154,326	89.9
not suitable (water)	16,422	7.8	12,660	7.4
not suitable (soil)	6,647	3.1	4,688	2.7
not suitable (soil & water)	295	0.1	73	0.0
Total	**211,554**	**100**	**171,747**	**100**

Table 4.1 summarizes the land evaluation exercise above. In total ~212,000 ha are planted with coffee of which ~188,000 ha are suitable (89%). Areas not suitable for coffee production in terms of soil and topographic conditions count ~7,000 ha (3.2%). 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 ~16,500 ha (7.8%). These land units will be included in the landscape model but converted into less water demanding mixed cropping systems without coffee. About 81% of the current coffee area lies within the 2S basin.

4.2 Crop water requirements and current actual water use

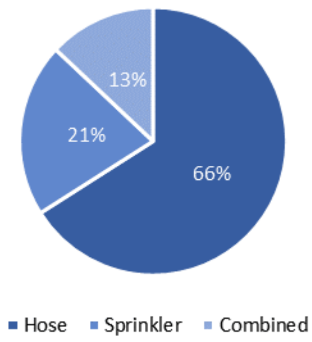
4.2.1 Robusta coffee

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[2]), 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 4.2). In order to calculate the landscape wide water requirement, the irrigation method needs to be taken into account as some methods are more or less efficient than others.

[2] 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).

Figure 4.2 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, the 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 taking into account evaporative water losses on the canopy, the sprinkler method requires about 45% more water i.e. ~600 l/tree/round (Table 4.2).

Table 4.2 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

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 620,000 farmers (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 4.3 and Figure 4.4).

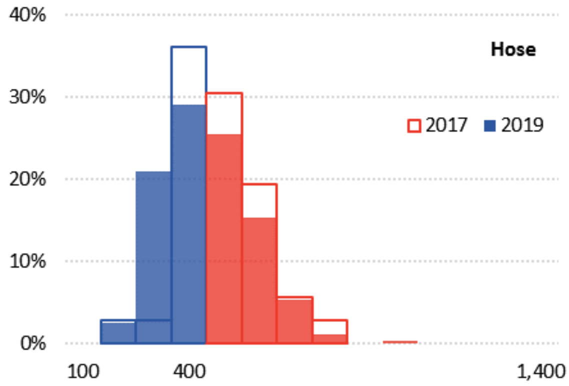


Figure 4.3 Adoption rates on good irrigation practices in 2017 and 2019 (hose)

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).

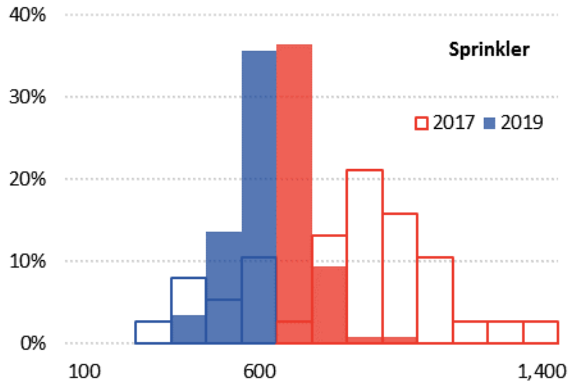


Figure 4.4 Adoption rates on good irrigation practices in 2017 and 2019 (sprinkler)

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 4.2) will be used in the landscape modeling described below.

4.2.2 Intercrops: pepper, avocado and durian

The crop water requirements for alternative intercrops are taken from WASI and summarized in Table 4.3 below.

Table 4.3 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	Irrigation volume
	(#/ha)	(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

4.3 Crop modelling

4.3.1 Crop life cycle

Based on literature review and discussion with experts the respective crop life cycles for Robusta coffee (Coffea canephora), black pepper (Piper nigrum), Avocado (Persea americana) and Durian (Durio) were developed (Figure 4.5 and Table 4.4). The latter three species were selected as potential intercrops since they are recommended by WASI.

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 4.4 gives on overview of the life cycle stages and maximum potential yields for all four crop species.

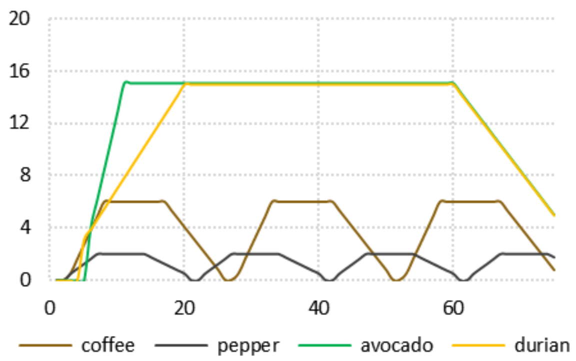


Figure 4.5 Crop life cycle by crop species (t/ha)

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.

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

Table 4.4 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

4.3.2 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 4.3.1). The simulated production figures (t/ha) were plotted in a matrix form. Columns depict the production years, rows the rejuvenation cycle years (Figure 4.6, 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).

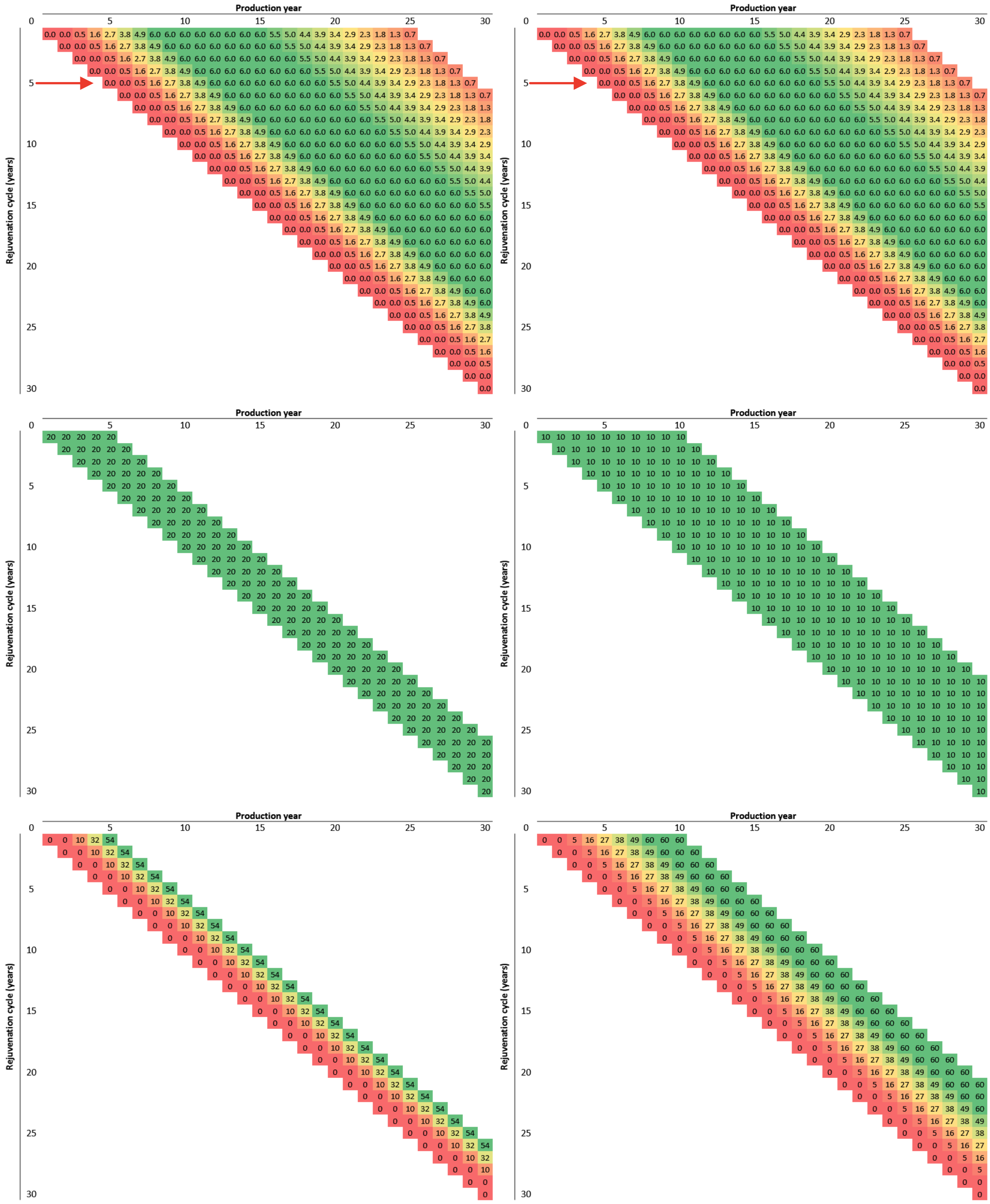


Figure 4.6 Coffee life cycle, rejuvenated area and total production for 5 (left) and 10 (right) years

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 4.6). 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 4.6 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 4.6 (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 301-dimentional matrices (2 are shown as an example in Figure 4.7).

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 4.7 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.

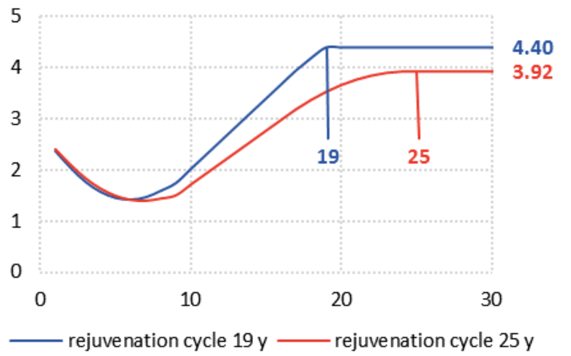


Figure 4.8 Simulation of monocrop coffee production over time for two rejuvenation cycles

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 4.8 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 life time 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 (i.e. ~11,000 ha conversion annually). 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 year 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.

4.3.3 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 hectare) in the current coffee areas (~212,000 ha in Dak Lak; cf. section 4.1). 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 4.3.2). At landscape level a 19-year rejuvenation cycle is equivalent to ~11,000 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 4.1) which shows that ~188,000 ha is suitable for coffee production, while ~ 16,000 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.

4.3.4 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. The gross revenue is calculated by multiplying the annual yield (t/ha) by average annual price (USD/t) per the crop species. Average annual crop prices were derived from various sources (Figure 4.9 and Table 4.5).

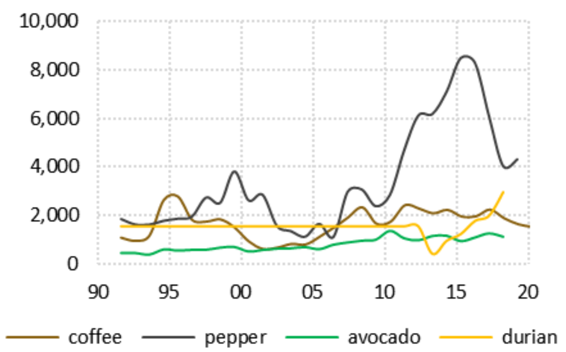


Figure 4.9 Historic annual average crop price

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 4.5 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 4.9)

Crop	Price
Coffee	1,650
Pepper	3,399
Avocado	793
Durian	1,556

To maximize gross revenues[3], we need to identify the best combination of crop species in terms of plants per hectare. Multiple goal linear programming was applied to resolve this problem. 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 25% 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 4.6 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 4.6 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:	25% 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

[3] 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 25% in fully diversified cropping systems.

4.3.5 Calculation of investment costs and Return on Investment

To investigate the investment needs, a budget was constructed over a 30-years 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 a large-scale investment program, the Return on Investment (RoI) was calculated according to Equation 4.1.

Equation 4.1 Return on Investment

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

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

4.3.6 Carbon sequestration

To understand the effect of crop diversification on climate change mitigation potential, 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 to significantly carbon sequestration.

Equation 4.2 Aboveground biomass for coffee

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

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

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

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 Dak Lak) shows that the yield in year 1 for monocrop coffee rejuvenated over 19 years, is about 500,000 metric ton (Figure 5.1). This is in line with actual figures reported for the 17/18 crop year in Dak Lak (i.e. 470,000 t; USDA GAIN, 2018). Under monocrop (BaU) conditions, the provincial output reduces to a minimum of 299,000 t in year 6 (-40% vs. year 1), then recovers to break even in year 12 (543,000 t) to reach a stable production of 930,000 t as of year 19. This is 86% 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 (pepper, avocado and durian), total provincial production drops to a minimum of 260,000 t in year 7 (-48% versus year 1), then climbs to a break-even point in year 15 (519,000 t), reaching stable production in year 19 (661,000 t). This is 32% higher compared to year 1.

In the intercrop scenario, total provincial production for pepper, avocado and durian will reach an annual stable maximum of 50,000 t, 405,000 t and 334,000 t respectively in year 25 (Figure 5.2).

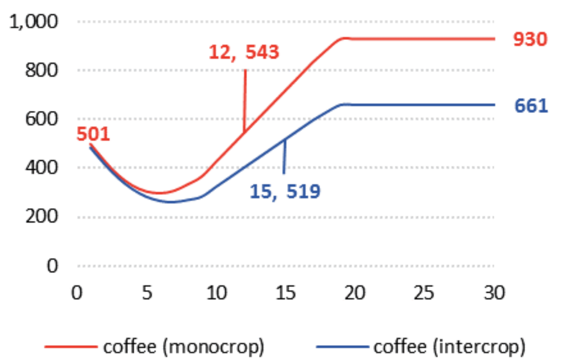


Figure 5.1 Annual coffee production at landscape level

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

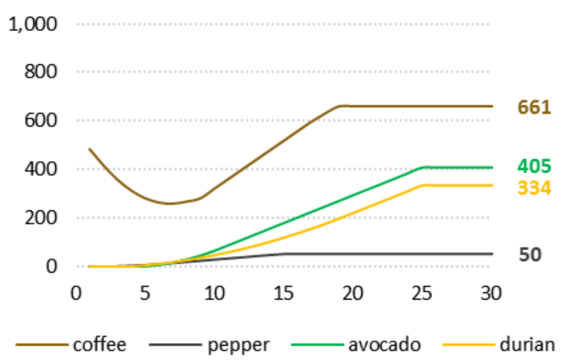


Figure 5.2 Annual production per crop species at landscape level

For each crop species the total annual production for Dak Lak province is shown (kt/y).

5.1.2 Higher gross revenue through diversified farming

In terms of gross revenue generation, the BaU scenario (monocrop coffee) at landscape level results in an average net annual value addition of 83%, i.e. 1.53 billion USD/y in year 19 compared to 0.83 billion USD in year 1 (Figure 5.3) at an average coffee price of 1,650 USD/t. For the intercrop scenario the value addition in year 25 is 2.5 times higher compared to year 1 or 37% 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).

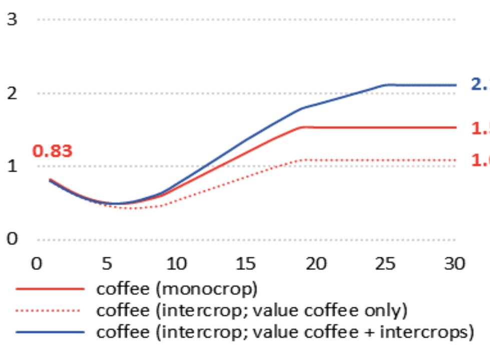


Figure 5.3 Annual gross revenue at landscape level

The full red line depicts the BaU scenario, the red dashed 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 1991 until 2018.

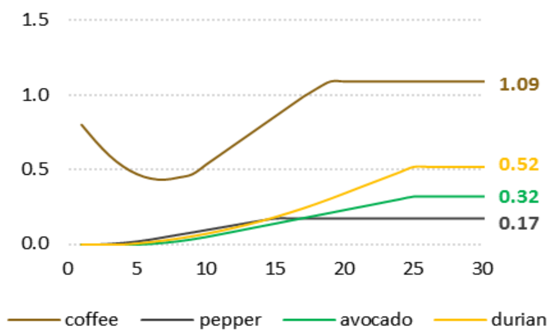


Figure 5.4 Annual gross revenue by crop species at landscape level

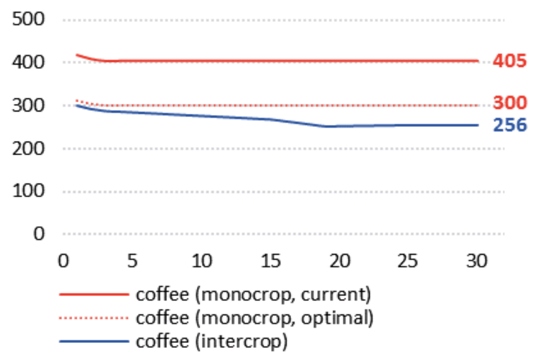
The annual gross income is broken down per crop.

The gross income (billion USD) is calculated based on the average crop price from 1991 until 2018.

5.1.3 More coffee and other crops with less water

At the provincial level (Dak Lak), monocrop coffee under current excessive irrigation conditions consumes about 405 million m3 water per year (Figure 5.5). If irrigation management is optimized for monocrop coffee about 105 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 149 million m^3 of water can be saved as of year 19 compared to the BaU (-37%). Based on the land suitability analysis (cf. chapter 4.1), about 81% of the coffee area in Dak Lak lies within the 2S boundaries. Hence circa 120 million m^3 of water can be saved at the 2S watershed level.

Optimization of water use goes hand in hand with cost savings for labor and energy. About 14 million USD can be saved annually. Out of the total irrigation cost, 42% goes to labor and 58% to energy (Figure 5.6)



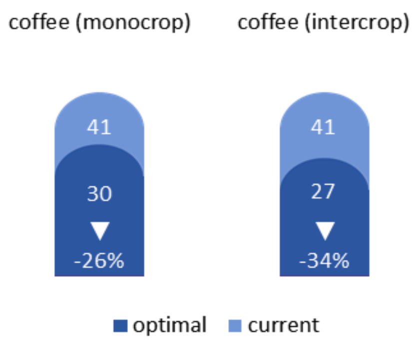


Figure 5.5 Water use per scenario at landscape level

The red full line depicts the BaU scenario (excessive irrigation), the red dashed line is the BaU for optimized irrigation and the blue line shows the fully intercropped model with optimal irrigation (mio. m3).

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 suggests an investment projection over 30 years, with focus on a large-scale training program for farmers 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 traders and end-buyers) through professional agricultural extension experts. In the below investment overview (Table 5.1) it is assumed to train 100 extension officers and agronomists over the first 5 years (12 training days per year).

Subsequently, the extension officers provide farmer training in traditional Farmer Field Schools for groups of 25 farmers, but additionally and complementary in one-to-one Farmer Coaching Visits. Through the latter approach, 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.

In parallel it is suggested to invest in nurseries to produce coffee, pepper, avocado and durian seedlings. Table 5.1 presents an estimate of the total investment costs for a 30-year horizon, which is estimated at ~310 million USD. This is equivalent to ~50 USD per farmer per year (assuming 1 ha per farming family).

Table 5.1 Investment projection over 30 years for Dak Lak Province

Values are expressed in USD

The budget shows total gross figures over 30 years

Investments	# Units	Unit	Unit Cost	Total Cost
Training program				**21,890,000**
Training of Trainers	60	# sessions	1,282	77,000
Farmer Field Schools	98,400	# sessions	21	2,103,000
Farmer Coaching Visit	1,845,000	# visits	11	19,710,000
Seedlings				**263,632,000**
Coffee	300,000,000	# seedlings	0.34	102,553,000
Pepper	210,000,000	# seedlings	0.17	35,894,000
Avocado	15,000,000	# seedlings	2.14	32,048,000
Durian	18,000,000	# seedlings	5.13	92,297,000
Establishment nurseries	262	# nurseries	3,205	840,000
Awareness raising campaigns				**1,539,000**
TV spots	120	# campaigns	12,819	1,539,000
Personnel				**16,103,000**
FFS trainers	7,200	man-months	427	3,077,000
FCV trainers	28,800	man-months	427	12,307,000
Agronomists	240	man-months	1,709	411,000
Program manager	120	man-months	2,564	308,000
Other				**5,128,000**
Transport	30	year	170,920	5,128,000
Grand total				**308,292,000**

Figure 5.7 and Figure 5.8 show the cumulative annual program investment versus the cumulative added value (difference between monocrop coffee and fully diversified farming) at the landscape level. It is obvious that the added value significantly offsets the investment costs. The ROI breaks even in year 10 (i.e. ROI = 0) and reaches ~4 in year 15. I.e. for every dollar spent 4 USD are earned.

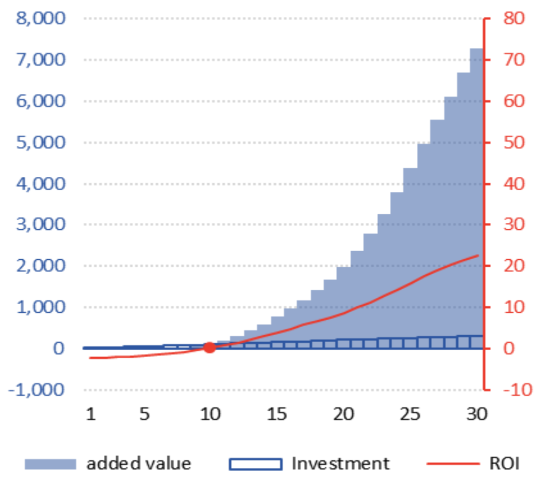


Figure 5.7 Cumulative investment and cumulative added value vs. BaU at landscape level

Added value (mio. 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.

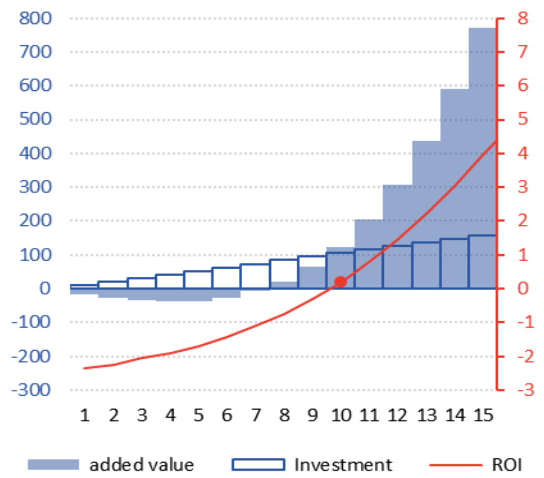


Figure 5.8 Cumulative investment and cumulative added value vs. BaU at landscape level

This graph is identical to the graph at the left (Figure 5.7) but scaled to a time horizon of 15 years (mio. USD).

5.1.5 Carbon sequestration potential for Dak Lak

Based on simple allometric equations, the potential for carbon sequestration was calculated for the business as usual scenario (monocrop coffee) and for a fully intercropped farming system. The simulation assumes for both scenarios that the current (i.e. simulation year 1) landscape wide coffee tree stock has an average age of 15 years. This is equivalent to a carbon stock of 2,060 tons (Figure 5.9). For monocropping, the carbon stock gradually reduces and stabilizes at 1,372 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 2,491 t at landscape level or 81% higher compared to the BaU scenario. 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 5.22 in chapter 5.2.5).

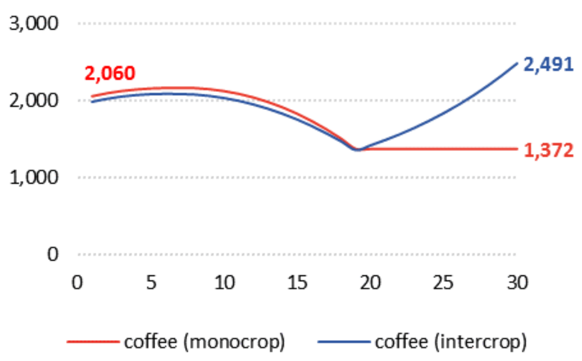


Figure 5.9 Carbon sequestration over time for monocrop and intercropped coffee (landscape)

The x-axis shows the timeline (y) and the y-axis the carbon sequestered (t).

The blue line is coffee only (1,110 trees/ha) and the red 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.

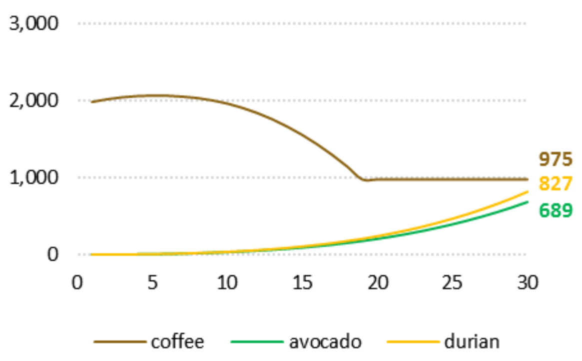


Figure 5.10 Carbon sequestration over time broken down by crop species (landscape)

The x-axis shows the timeline (y) and the y-axis the carbon sequestered (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 the business as usual scenario (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 monocrop (BaU) conditions the farm output reduces to a minimum of 1.41 t/ha in year 6 (-40% vs. year 1) and then recovers to a break-even point 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 trees per hectare (-20%). In this scenario, the yield drops to 1.29 t/ha in year 7 (-48% 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 32% 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 drop in yield and consequent income loss are partially compensated by the upcoming production of the intercrops (cf. chapter 5.2.2).

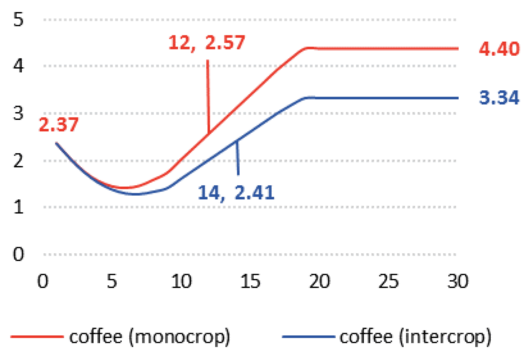


Figure 5.11 Annual coffee production at farm level

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

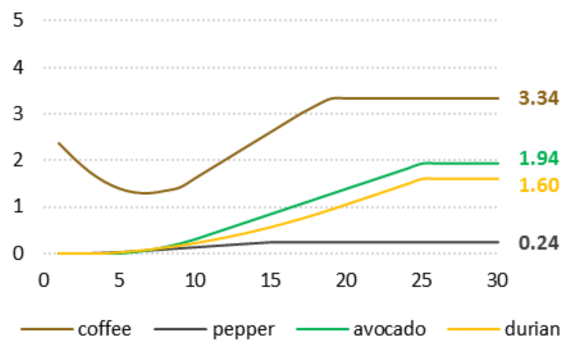


Figure 5.12 Annual production per crop species at farm level

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 years' time horizon a farmer's average annual gross income could theoretically increase from ~3,900 USD/ha (monocrop coffee in year 1) to ~5,300 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 mixed farming, the average annual gross revenue could go up to ~6,600 USD/ha.

It is important to note that gross revenues will be less compared to the current situation for the first 5 to 10 years. As a consequence, adequate support measures (e.g. insurances, subsidies, tax levies, etc.) may need to be developed to support smallholder farmers during the agricultural transformation process.

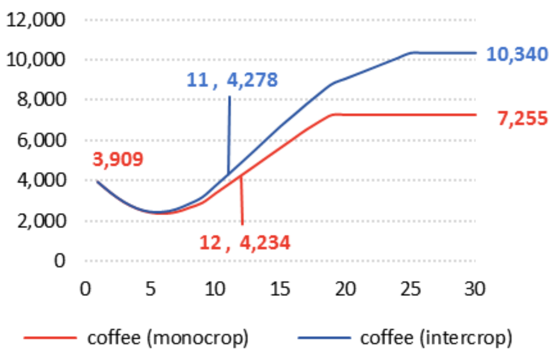


Figure 5.13 Annual gross farm income

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.

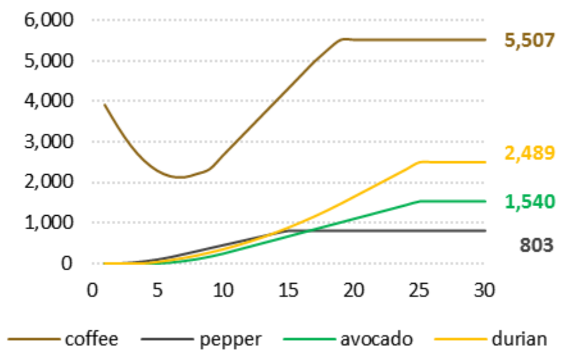


Figure 5.14 Annual gross farm income by crop species

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

In an effort to more realistically sketch 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 a downward trend in annual coffee prices is observed (2017-2019). 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).

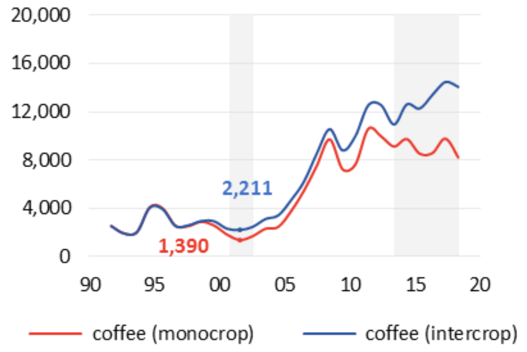


Figure 5.15 Annual gross farm income based on historic crop price

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 actual calendar years from 1990 to 2020.

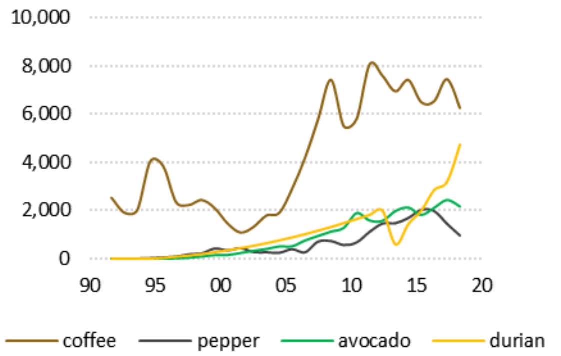


Figure 5.16 Annual gross farm income by crop species based on historic crop price

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 actual 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.

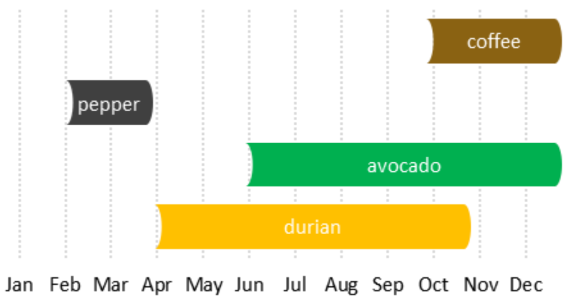


Figure 5.17 Harvest period per crop species

5.2.4 High return on Investment

Assuming that the farmers cover the cost for training and purchase of seedlings to rejuvenate and diversify the farm (i.e. investment), the ROI at the individual farm level breaks even in year 5 (i.e. ROI = 0) and reaches 5.3 in year 15. I.e. for every dollar spent 5.3 USD are earned (Figure 5.18 and Figure 5.19).

The annual average investment is estimated at ~58 USD/ha, summing to a total cumulative value of 1,752 USD/ha over 30 years.

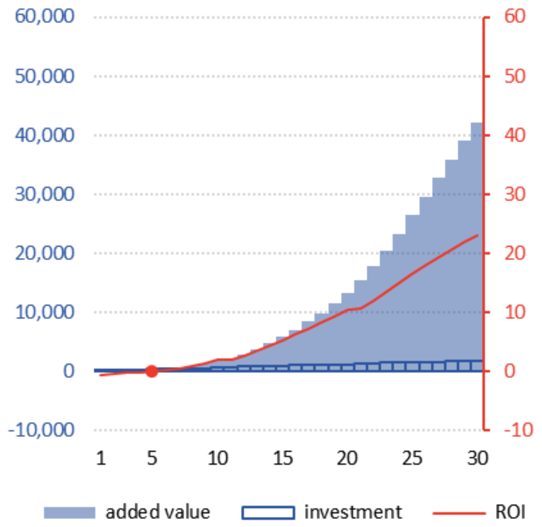


Figure 5.18 Cumulative investment and cumulative added value at farm level

The added value (USD/ha) 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 crop varieties and application of good agricultural practices.

The red line depicts the annual return on investment; the red dot on this line indicates the year where the ROI exceeds zero.

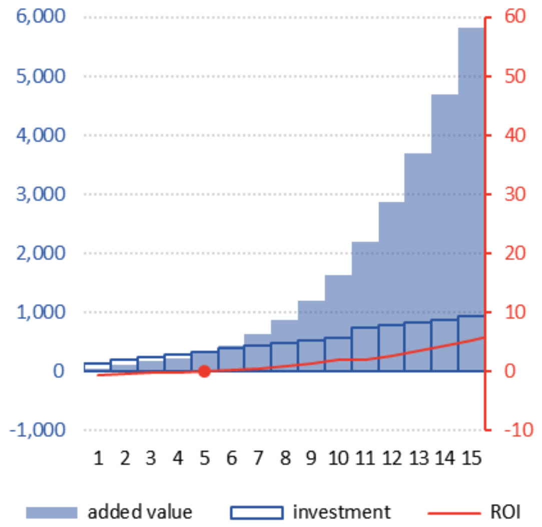


Figure 5.19 Cumulative investment and cumulative added value at farm level

This graph is identical to the graph at the left (Figure 5.18) but scaled to a time horizon of 15 years (USD/ha).

The red line depicts the annual return on investment; the red dot on this line indicates the year where the ROI exceeds zero.

5.2.5 Increased carbon sequestration

Figure 5.20 shows similar 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).

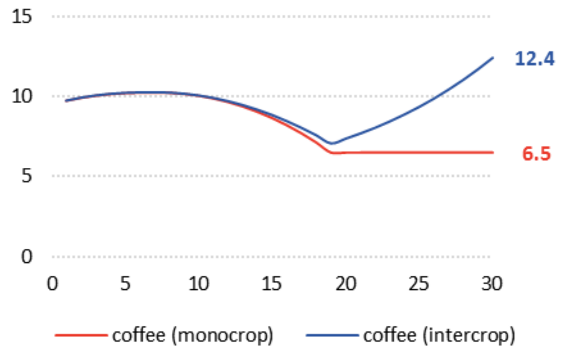


Figure 5.20 Total carbon sequestration for monocrop and intercropped coffee over time

The x-axis shows the timeline (y) and the y-axis the carbon sequestered (t/ha).

The blue line is coffee only (1,110 trees/ha) and the red 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.

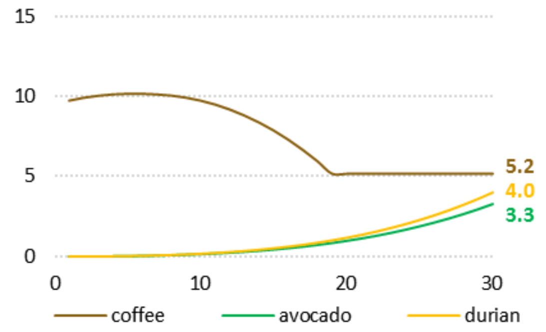


Figure 5.21 Carbon sequestration for intercrop systems over time broken down by crop species

The x-axis shows the timeline (y) and the y-axis the carbon 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 5.22 shows the carbon sequestration over time assuming monocrop farming (without rejuvenation after 19 years). For a mature coffee plantation of 15 years ~10 tons carbon is captured per hectare. 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 in the range of 9.4 to 13.2 t/ha in the Central Highlands.

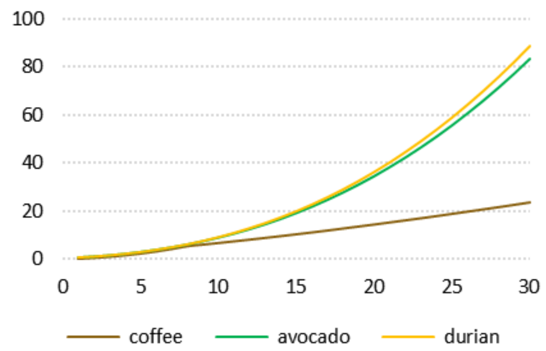


Figure 5.22 Carbon sequestration for monocrop systems over time broken down by crop species

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 Conclusions and Recommendations

6.1 Economic gains – production and gross revenue

a. Transformation of monocrop coffee farming does not put overall coffee production in Dak Lak 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 32%. Current production stands at ~501,000 t, while stable potential production is estimated at 661,000 t as of year 19 onwards.
b. Production of selected intercrops, i.e. pepper, avocado and durian, will increase to respectively 50,000 t, 405,000 t and 334,000 t as of year 25 onwards. It remains to be seen whether the market can absorb the increased production of the chosen intercrops.
c. At the farm level, increased coffee production (average yield increase from 2.37 t/ha to 3.34 t/ha) and additional intercrops will generate significantly higher gross revenues (+43%). As of year 25 onwards, monocrop coffee is estimated to generate ~7,255 USD/ha/y, while diversified farming would bring about ~10,340 USD/ha/y (under constant prices). The break-even point (compared to year 1 monocrop coffee) is reached in year 11.

6.2 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 405 million m^3 water per year in Dak Lak province. If all farmers were to optimize irrigation volumes in this scenario, ~105 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 ~256 million m^3 per year in Dak Lak province. In this case 149 million m^3 of water can be saved as of year 19 compared to the BaU (-37%).
c. Given that about 81% of the coffee area in Dak Lak lies within the 2S boundaries, circa 120 million m^3 of water can be saved at the 2S watershed level annually (in Dak Lak only).
d. Optimization of water use goes hand in hand with cost savings for labor and energy. About 14 million USD can be saved annually. Out of the total irrigation cost, 42% goes to labor and 58% to energy.
e. Compared to monocrop coffee production, fully diversified farming returns carbon sequestration gains in the order of 81%. Carbon capturing for monocrop coffee will reach ~1,372 t/ha in year 30. For intercropped farming systems this will increase to ~2,491 t/ha at the landscape level.

6.3 Intervention strategy – costs and return on investment

a. To realize agricultural land use transformation for Dak Lak, it is suggested 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 suggested to invest in nurseries to produce coffee, pepper, avocado and durian seedlings.
b. The investment projection for such a long-term program is estimated at ~310 million USD over 30 years. While this figure may look high, it is equivalent to only about 50 USD per farmer per year (assuming 1 ha per farming family) or ~1,500 USD per ha over 30 years.

c. The ROI breaks even in year 10 and reaches ~4 in 15 years at landscape level. At the farm level, the ROI breaks even in year 5 and becomes 5.3 in year 15, meaning that for every USD spent 5.3 USD are earned.

6.4 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 the cash at 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 provincial production for pepper, avocado and durian could possibly reach an annual outturn of 50,000 t, 405,000 t and 334,000 t 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.
d. The model simulations suggest that both at landscape and farm level high ROI is likely after circa 11 years. A total investment of 310 million USD would be needed over 30 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 public extension services from the national level, over the provinces, down to the districts and communes, with extension officers paid by the government. 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 learns that the investment cost for training and acquisition of seedlings (~50-60 USD/ha/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 (e.g. World Bank VNSAT program). A third reflection for further discussion, refers to the payment of premium prices for so-called sustainable mainstream coffee. The roasting and retail industry tapped into certification over the last 2 decades as a means to promote and communicate about sustainable coffee production at a 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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