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Addressing smallholder resilience in coffee production in the Central Highlands, Viet Nam

The business case for intercropped coffee production

Summary

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Executive summary

Coffee production in the Central Highlands faces a multitude of challenges; decades of intensive cultivation and expansion onto marginal land has degraded the soil quality and left smallholders less resilient to both climate change and vulnerable to fluctuations in the price of coffee. As a result, many smallholders are in a negative spiral of declining yields leading to the increasing application of inputs to compensate, which is further reducing their already limited margins.

This analysis presents the business case for sustainable Robusta coffee cultivation in the Central Highlands region of Vietnam. In recent years, intercropping models involving coffee interspersed with shade or fruit trees have demonstrated their potential to generate multiple benefits to smallholders and the environment. This analysis focuses on the economic benefits of transitioning from an intensive coffee cultivation model to three different intercropping models: avocado, durian and cassia siamea and pepper, and makes recommendations concerning the transition pathway that will be most accessible to smallholders.

Even in poor market conditions, the analysis finds that diversifying a smallholding through the addition of another productive crop will generate economic benefits for the producer. Furthermore, the revenue generated through the addition of a crop can help to reduce the impact of periods of low coffee price on a smallholder's livelihood. However, while this will provide a degree of economic resilience to a smallholder, if the coffee price remains consistently subdued, it cannot be said that the smallholder will or should not make the economically rational decision to replace their coffee plantation with what they perceive to be a more lucrative or less volatile crop.

In addition to economic benefits, diversifying a smallholding can bring potential environmental benefits: leading to increased biodiversity and improved soil structure, that may further contribute to the economic profitability of the model by reducing the requirement for irrigation or agricultural inputs and increasing resilience to climate driven drought or flooding.

The initial capital expenditure for converting to intercropping with durian, avocado, cassia siamea and pepper varies between VND 5.7 million for Avocado and VND 10.8 million for cassia siamea and pepper. While the additional operational expenditure varies between VND 628 thousand for durian and VND 12.24 million for cassia siamea and pepper.

Due to the added capital and operational expenditure requirements and the delay in revenue until the intercropping plant becomes productive, transitioning to a diversified production model may be inaccessible for poorer households without access to additional financing.

The analysis demonstrates ways in which converting to intercropping can be made more accessible to poorer households, by (i) initiating the transition earlier in the lifecycle for the coffee plantation, when the coffee plants are more productive and therefore generate a higher revenue and by (ii) staggering the transition over a number of years, thereby reducing the annual capital expenditure.

Further work is required to fully understand each model's resilience to the changing environmental and economic conditions. For example, irrigation is presently free for smallholders across the Central Highlands, but in the near future, due to water shortages, irrigation could be restricted or provided at cost, adding an additional operational cost to production. Similarly, recent socio-economic trends have seen a decline in the availability of labour, which will also likely impact the economics of smallholder production as labour costs increase.

1. Background: Coffee production in Vietnam

Vietnam is the second largest exporter of coffee globally (behind Brazil), and the largest for the Robusta variety. Between the mid-1980s and 2000, Vietnam's harvested coffee area expanded from 15,000 to nearly 500,000 hectares,[1] driven in part by the economic reform that was being undertaken in the country.[2] The same programme of reform also provided support for internal migration from more land-constrained regions, as well as investments in rural infrastructure. It was during this period that much of the most suitable land was converted for coffee cultivation.[3]

The Central or Western Highlands is the main growing area for Robusta coffee in Vietnam. It is a highland region in Central Vietnam comprised of five provinces: Dak Lak, Dak Nong, Gia Lia, Lam Dong and Kon Tum. Robusta coffee production from these five provinces together accounts for 92% of the total national production, which is currently grown on roughly 577,000 ha.[4]

In recent years, coffee has demonstrated its potential to generate high revenues in the Central Highlands, making the crop very attractive for smallholder cultivation. Since the 1980s, coffee production in Vietnam has increased by nearly two orders of magnitude, from roughly 19,400 tonnes/year to 1.76 million tonnes in 2016.[5,6] This rapid growth in output has been a function of both increasing the area of land under cultivation and the adoption of intensive farming practices; Vietnamese farmers typically achieve yields of more than 3.5 tonnes per hectare, whereas Robusta yields per hectare average 0.8 tonnes in Thailand, 0.5 tonnes in Indonesia, and 0.4 tonnes in Laos.[7]

While this growth has made a significant contribution to the Vietnamese economy, it has not come without cost. Maintaining these high levels of productivity has created a series of environmental challenges, including deforestation and land degradation. As a result much of the expansion took places on marginal land unsuitable for coffee cultivation, and decades of excessive fertilizer and agrichemical application has contributed to the gradual deterioration of the soil, leading to issues with soil fertility, disease and nematode infestation.[8,9] These issues will be further compounded by the changing weather patterns that are expected as a result of climate change. They will lead to a significant reduction of land suitable for coffee cultivation and of water available for irrigation.[10]

2. Problem statement

Smallholder output in the Central Highlands is low quality, low volume and environmentally unsustainable

Smallholder production accounts for roughly 80-90% of Robusta coffee from the Central Highlands.[11,12] Smallholder cultivation practices are typically intensive and costly; characterized by the high application of pesticides, fertilizers and irrigation,[13] but, while Vietnam's coffee yields are above international norms, they have barely progressed over the past decade. Several factors account for this, including the aging of the tree stock, the spread of coffee planting onto less suitable or unsuitable land, and various episodes of drought (1999, 2005, 2013).[14] As a result, maintaining high yields has become a function of the heavy application of fertilizer and pesticides.[15] Soil testing in Vietnam is rare and subsequently, farmers often do not apply fertilizer of the optimal composition or at the optimal time. For a smallholder, the risk of a reduced yield due to under-application of fertilizer is considered less than the risk of the over-application of fertilizer.

Excessive fertilizer use, together with weak water management practices, has led to a large proportion of fertilizer running off into streams and groundwater, and emissions into the atmosphere as nitrous oxide, a potent greenhouse gas. Consequently, between one-half and two-thirds of fertilizer nutrients are not taken up by crops.[16] The long-term impacts of excessive application of fertilizer and other agricultural inputs has been shown to increase soil acidification and soil hospitability to nematodes and plant diseases, which in turn reduces soil and fertility, requiring increasing levels of fertilizer to compensate for reduced productivity.[17] This leads to increasing capital requirements for the purchase of fertilizer and other agrichemical input. For poor farming households, it is often difficult to generate cashflow to support these working capital requirements, but without sufficient investment in agrichemical input, the overall productivity, and quality and quantity of the coffee beans is likely to be lower and generate lower levels of income for farmers, which leads to a vicious circle where smallholders cannot generate future working capital for input and labour, and so on. For example, the International Fund for Agricultural Development (IFAD) has shown that productivity could be as low as 1.2 tonnes/ ha for farmers who are unable to invest in sufficient levels of key input, while farmers with higher capacity to invest productivity it could be as much as 3.5 tonnes /ha of coffee beans.[18]

Compounding these issues, smallholders are also the most economically disadvantaged participants in the coffee value chain: due to their relatively low output they face higher transaction costs in order to sell to distant markets. Typically, they also have limited access to finance and legal recourse, and as a result are almost entirely dependent on decisions made by downstream participants.[19]

Smallholder livelihoods are vulnerable to changes in the price of coffee

Intensive monocrop coffee cultivation leaves farmers vulnerable to changes in the market price of Robusta.[20,21,22] This is compounded by relatively low levels of domestic consumption and exposure to an international market that is clustered around the production of a small group of countries - Vietnam, Brazil, and Indonesia - which together account for roughly 75% of global production.[23] In consequence, global price is highly responsive to changes in the weather and growing conditions in those countries, leading to increased market volatility.

Significantly, low price expectations deter producers from making investments to improve their production capacity or increase resilience, which contributes to greater producer insecurity; investments in substantial cultivation improvements increase both capital and operational expenditure. At times when margins are depressed due to low market prices, this impacts the economic rationale for such an investment.

This can lead to a vicious cycle for producers; lower levels of investment lead to the production of lower quality coffee and lower yields. This reduces earning expectations and increases exposure to emerging or unforeseen risks such as climate change. For smallholders this risks their livelihoods, and for global supply chains, it increases the risk of destabilizing the supplier base.

Economic uncertainty can also increase the threat of further expansion into forests, as smallholders seek to increase their livelihood. Investments in substantial cultivation improvements in coffee supply chains increase both capital and operational expenditure. At times when margins are depressed due to low market prices, this affects both the economic rationale of such an investment and also the credit risk represented by smallholders borrowing in order to finance their own investment.

3. Proposed solution for analysis: Intercropping coffee with fruit trees

Intercropping models involving coffee interspersed with shade or fruit trees have demonstrated their potential to generate multiple benefits for intensive coffee cultivation models and smallholder livelihoods. These benefits can include:[24,25]

Enhancing functional biodiversity and improving soil fertility

Shade tree species can contribute to improving, preserving or restoring soil fertility and buffering seasonal variability of soil biological activity in intensively managed coffee farms.[26] Shade trees in agroforestry have also been found to increase functional biodiversity, carbon sequestration, and drought resistance, as well as weed and biological pest control.[27,28] This implies that shade trees could lead to reductions in the need for agricultural chemicals, pesticides, and herbicides, which could collectively lead to reduced soil and water pollution, as well as a potential reduction in costs for smallholder producers.

Improvements to soil health, leading to better soil water storage capacity

Decades of the excessive application of agrichemicals has led to a reduction in soil quality in coffee plantations in the Central Highlands, leading to issues with disease and nematode infestation.[29] Advances in soil biodiversity will improve soil structure and moisture retention, thus reducing the need for irrigation.[30]

Turning farms from carbon sources to carbon sinks

A recent study by IDH (the sustainable trade initiative) showed that while highly diversified farmers growing non-coffee trees on their farm had higher carbon dioxide equivalent (CO_2e) emissions, as a result of short-term increases in agricultural chemical application, transport, and so on, the higher rate of carbon dioxide (CO_2) sequestration from accumulated biomass, combined with improved fertilizer use could reduce the climate impact of farms, turning them from net sources to net sinks.[31]

Improvements to smallholder livelihoods

Finally, productive fruit and shade trees have the potential to provide an additional income for smallholders from the sale of timber, firewood or fruits, the revenue from which could improve smallholder livelihoods, as well as lessening the impact of a reduction in coffee yield or a reduction in coffee prices on smallholder livelihoods.[32,33]

Given the multiple potential benefits provided by shade and fruit trees, intercropping was selected as the model with the greatest potential to generate immediate improvements to the coffee landscape in the Central Highlands, while potentially improving livelihoods and stabilising incomes for smallholders.

4. Methodology of assessment

An analysis was carried out in separate stages to understand the suitability of intercropping as an alternative cultivation model in the Central Highlands: (I) assessment of the enabling environment, a market and value-chain assessment to understand the capacity for intercropping markets to absorb additional production; (II) an assessment of cost, and the benefits of conversion to diversified agriculture; and (III) an assessment of the resilience of models to changing market conditions.

I. Assessment of the enabling environment

Qualitative and quantitative assessment was undertaken to understand the capacity for intercropping commodity markets to provide a viable livelihood for smallholders. Potential markets were assessed according to their:(i) capacity to absorb additional supply, levels of domestic and global consumption, (ii) access to local and global markets for smallholders; and (iii) global market outlook.

Increasing the level of supply of goods into a market will typically lead to a reduction in the price of those goods. For smallholders, this could mean the difference between making a profit and making a loss. It is therefore necessary to have some insight into how the market will respond to a change in the quantity of goods supplied. The magnitude of that reduction is determined by a number of factors and is described by the price elasticity of demand.

To understand the price elasticity of demand, demand curves were first constructed for each commodity using data on individual trades, export values and volumes from the UN Comrade database.[34] A regression of the price and log of the net weight for each trade was carried out to determine the relationship between export price and weight for each commodity.

II. Assessment of the economic feasibility of the solutions

On the basis of the initial findings from the market assessment, three potential intercropping models were selected for analysis of the economic benefits and costs to smallholders. These were: coffee intercropped with durian, coffee intercropped with avocado and coffee intercropped with cassia and pepper.

An analytical tool was developed using Excel that modelled future cash flows for smallholders under a range of different scenarios. The tool predicts the economic impact of certain on-farm decisions from the perspective of a smallholder who is currently farming coffee intensively. A list of the decisions modelled is shown in Table 1.

Table 1: Different on-farm decisions for the smallholder, modelled by analytical tool

On-farm decision	Production system
Continue Intensive coffee cultivation without rejuvenation (baseline)	Coffee monocrop (no rejuvenation)
Rejuvenation of coffee	Coffee monocrop
Conversion from coffee monocrop to intercropping (with/without rejuvenation of remaining coffee)	Coffee-Durian
	Coffee-Avocado
	Coffee-Cassia
	Coffee Cassia/Pepper

Description of smallholder choices modelled:

Baseline - coffee monocrop
The baseline assumes the farmer makes no choice to rejuvenate or to convert to intercropping.

Variable rejuvenation period coffee model (no intercropping)
This model demonstrates the choice of a farmer to rejuvenate their crop, demonstrating the impact of changing the period of rejuvenation.

This model enables an assessment of the impact of starting the rejuvenation process at different plantation ages and how that will affect cash flow. This is important because as coffee plants age, their productivity decreases, therefore the rate of rejuvenation impacts cash flows differently, depending on the age and productivity of the remaining coffee. The intuitive assumption is that the lower the productivity of the remaining coffee, the faster the rejuvenation should occur.

Leaving a field fallow has been included as an option in order to match the situation observed in farms in the Central Highlands; farmers are having to leave their fields fallow in order to replenish the soil biota that have depleted after years of excessive agrichemical application.

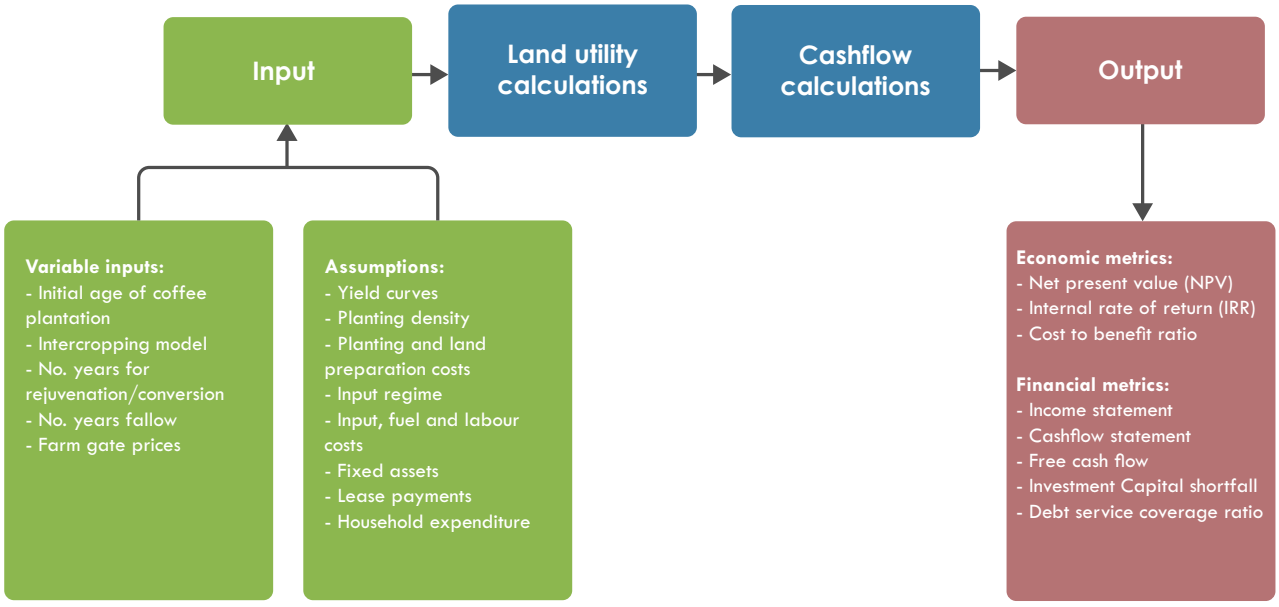
It is currently assumed that a farmer will continue to irrigate their field during the fallow period in order to prevent it drying out. The model also assumes that land preparation occurs at the beginning of the fallow period, and replanting occurs at the end of the fallow period, however, it is not clear whether this reflects common farming practices in the Central Highlands.

Conversion to intercropping
This model demonstrates the choice of a farmer to convert their smallholding to intercropping. The four options that can be selected are: coffee-avocado, coffee-durian and coffee-cassia with or without pepper.

The model allows the user to select the following: the rate at which the smallholding is converted, the age of the plantation when the conversion is initiated, and finally, observation of the impact on annual and cumulative cashflow.

It is possible to observe the cash flow implications of rejuvenating the coffee portion of the plantation either at same time and rate as they introduce intercropping or after waiting until the coffee crop is 25 years old, as recommended by the World Bank.

Figure 1: Structure of analytical tool



The model allows the user to select the rate at which the smallholding is converted and the age of the plantation when the conversion is initiated, and observe the impact on annual and cumulative cashflow.

III. Assessment of resilience of solutions to the changing prices

The initial prices for the analysis were those identified by Dr Nghia and his team through field research (Nghia et al. 2016),[35] however, markets are rarely stable, and it is necessary to understand how the models perform under different price regimes.

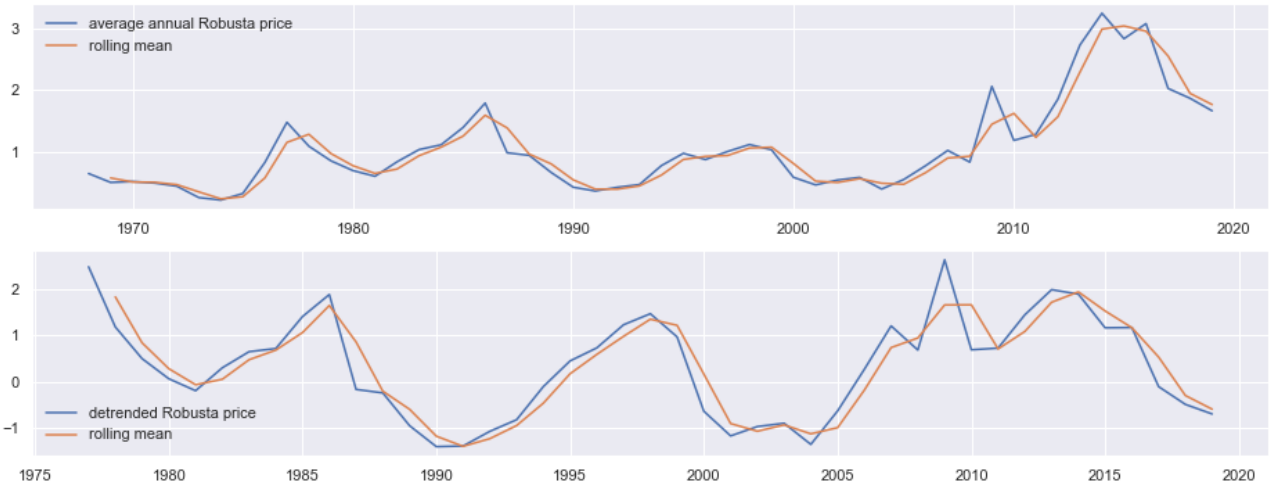
Understanding historic coffee price variability

Data on historic Robusta market prices from 1968 until 2018, is collected from the World Bank Commodity Price Database and adjusted for inflation using the World Bank global GDP deflator. The time series generated is shown in Figure 2.

Typically, volatility is common in commodity markets, and price stability is rare. This is clearly shown in the time series, which shows periods of high and low global market prices. The time series shows a downward trend between 2014-2015. This could be in part due to the combined impact of the rejuvenation programme, favourable growing conditions in the Central Highlands and higher output from the other coffee-producing countries. The increase in supply would be expected to exert downward pressure on the market price. This has led to fears that continued high levels of production could suppress the price of coffee to a point that farmers would no longer be able to ensure a reasonable standard of living,[36] reducing their resilience to any future shocks and potentially driving further deforestation in sensitive areas.

Analysis of the histogram and quantile-quantile plots generated from the pricing data suggested the time series does not follow a Gaussian distribution and is therefore non-parametric. This was confirmed by visual inspection of a quantile-quantile plot and through a Shapiro-Wilk test which showed a significant departure from normality (W= 0.963, p=0.001). In order to model the probability of certain prices being achieved, a Kernel Density Estimation (KDE), a non-paramedic method, was therefore used to estimate the probability density function for the global price of Robusta Coffee for the period 2008-2019.[37]

Figure 2: Inflation adjusted, annual global price for Robusta (1968-present (above)) and the de-trended time series for the same period with rolling mean (below).



The probability density function was used to assess the risk of a low price for coffee and its impact on the performance of the different intercropping models. Each of the cultivation models were tested to assess how they would perform under poor conditions to estimate the likelihood of:

- the minimum coffee price providing a sustainable livelihood for smallholders;
- the minimum coffee price to generate the investment capital for the conversion to intercropping;
- the likelihood that different intercropping production models would be economically viable for smallholder; and,
- under what conditions additional financial support would be necessary

Threshold prices assumptions for minimum price of coffee/intercropping for sustainable livelihood

- Assumption: farm gate price = 80% market price.[38]

Estimating farm gate fruit prices

Due to a lack of accurate farm-gate data for smallholder prices, the UN Comtrade database was used to access data on export price, collecting all pricing data on trades that originated in Vietnam from 2009-2018 for durian, avocado and pepper. The data was converted to price (USD) per kilogram. The interquartile range and the median were calculated. This allows estimations concerning the likely range of prices, without making any assumptions about the underlying statistical distribution, which was not feasible given the sparsity of data available.

Fruit markets are more fragmented and less developed than coffee markets, and therefore it was assumed that the resulting lack of price visibility would allow collectors to manipulate prices more than in coffee markets. In order to approximate the price difference, a conversion factor of 50% of the export price was used to approximate the farm-gate price. Further work would be needed to find a more robust way to understand how smallholder farm-gate prices respond to changing market prices.

5. Key findings and discussion

I. Assessment of the enabling environment

Intercropping coffee with shading tree models are becoming more popular in the Central Highlands. Some coffee companies have already begun to promote intercropping models to coffee farmers to both diversify incomes and improve sustainable practices. Commonly observed models include coffee-durian, coffee-avocado, coffee-Cassia siamea/pepper.[39] Indeed, many farmers have increased the area under intercropping areas as a result of the high earning potential of avocado, durian and pepper. The most commonly used intercropping production model with a forest tree is Cassia siamea, which can provide shade for coffee plants while also providing living posts on which to cultivate pepper. Typically, however models of coffee intercropped with forest trees, such as Cassia siamea, are less popular due to uncertainty over the short-term economic value of such a model.[40]

In the past 2-3 years, many farmers have begun to switch from producing coffee to growing other cash crops, such as black pepper, avocado, and passion fruit, in order to generate higher incomes. This change is reducing coffee areas, especially in Dak Lak, where arable land is limited. In other provinces like Dak Nong and Lam Dong, where arable land reserves are still available, the new arable land is used more for growing other crops.[41] Identifying the crops that can supplement smallholder livelihoods without reducing the area under coffee cultivation is therefore important for maintaining stability in the Robusta supply chain.

Commodities with market potential to support smallholder livelihoods

The market assessment showed that the crops and commodities best suited to providing a stable livelihood for smallholders were pepper, macadamia, avocado, durian, cassava and cashew. Based on these findings three potential intercropping models were selected for an economic analysis of the benefits and costs to smallholders: coffee and durian, coffee and avocado, coffee and cassia/pepper.[42]

Avocado
Avocado is not yet considered a market-oriented commodity in Vietnam. Until recently, avocado was primarily grown for the shelter from the wind that it provided to underling crops. Typically, avocado is farmed in small orchards of between five and ten trees, but dedicated orchards are also increasingly being cultivated.[43]

The main market for avocados grown in Vietnam is domestic. Recent years have seen a gradual increase in domestic demand, driven by rising urban incomes and awareness of the various health benefits, which has led to price increases. Growers are also motivated by potential access to a rapidly developing global export market driven by increasing demand from the EU, USA and Australia, which is logical considering Vietnam's competitive advantage as one of few countries in the world that has a suitable climatic condition for avocado cultivation.[44]

Pepper
The Vietnamese export market for pepper is far more developed than for avocado. Vietnam is one of the top pepper-exporting countries globally. Vietnam is well-connected to the international market for pepper, exporting 95% of its annual pepper production. Vietnam exports to 109 countries and territories, mainly to Europe, Asia and America.[45]

Roughly 80% of pepper production in the Central Highlands is exported internationally, providing smallholders with access to international markets.[46] As a result of surging global prices for pepper earlier in this decade, many farmers switched from coffee and planted black pepper. In some districts, pepper expansion cannibalized areas of rubber, cashew and coffee, as well as natural forest, however, while global demand is estimated to increase by 2% annually, supply is growing by 8-10%, according to the International Pepper Community (IPC).[47] This has led to an inevitable reduction in price over the last year.

Pepper is a climbing evergreen plant and as such needs a structure on which to grow. In the Central Highlands, it is common to grow pepper on living posts, such as Cassia siamea. Cassia siamea has the benefit of also providing revenue from the sale of fuelwood, from annually pruned branches, or timber, at the end of the lifecycle of the plantation.

Durian
In Vietnam, durian areas mainly cultivated in the South but there are some orchards in the Central Highlands in Lam Dong province at elevation of about 600 to 1000 mm. In 2017, Vietnam became a key importer of durian and 80%-85% of the imported durians are re-exported to China.

Impact of changing levels of supply on the market price for fruits

Results of the analysis shown in appendix III indicate that the price elasticity for pepper, macadamia, avocado, durian, cassava and cashew are low. This implies that even for large changes in the quantity of fruit supplied, the price response would be small. This may be an indication that local/global consumption is sufficient to absorb any additional production, without leading to a significant change in price. The analysis however does not take cross-commodity-elasticities or any kind of income and substitution effect into account.

II. Assessment of the economic feasibility of transitioning intercropping models

Economic benefits of intercropping compared with coffee-monocrop models

Intercropping with avocado, durian or Cassia siamea in combination with pepper, provides economic benefits to a smallholder over a 25-year period when compared with rejuvenating a coffee plantation in a single year, or a five-year or ten-year period.

Table 2 is a summary of the results, and shows the economic value in terms of net present value (NPV) and internal rate of return (IRR) for a smallholder converting to intercropping with durian, avocado, Cassia siamea or cassia siamea/pepper in either a single year, or a five-year period. Table 2 also shows the breakeven point, the point at which costs and revenue are equal.

Table 2: Comparing the economic benefits of different cultivation options for a smallholder, ranked by NPV*

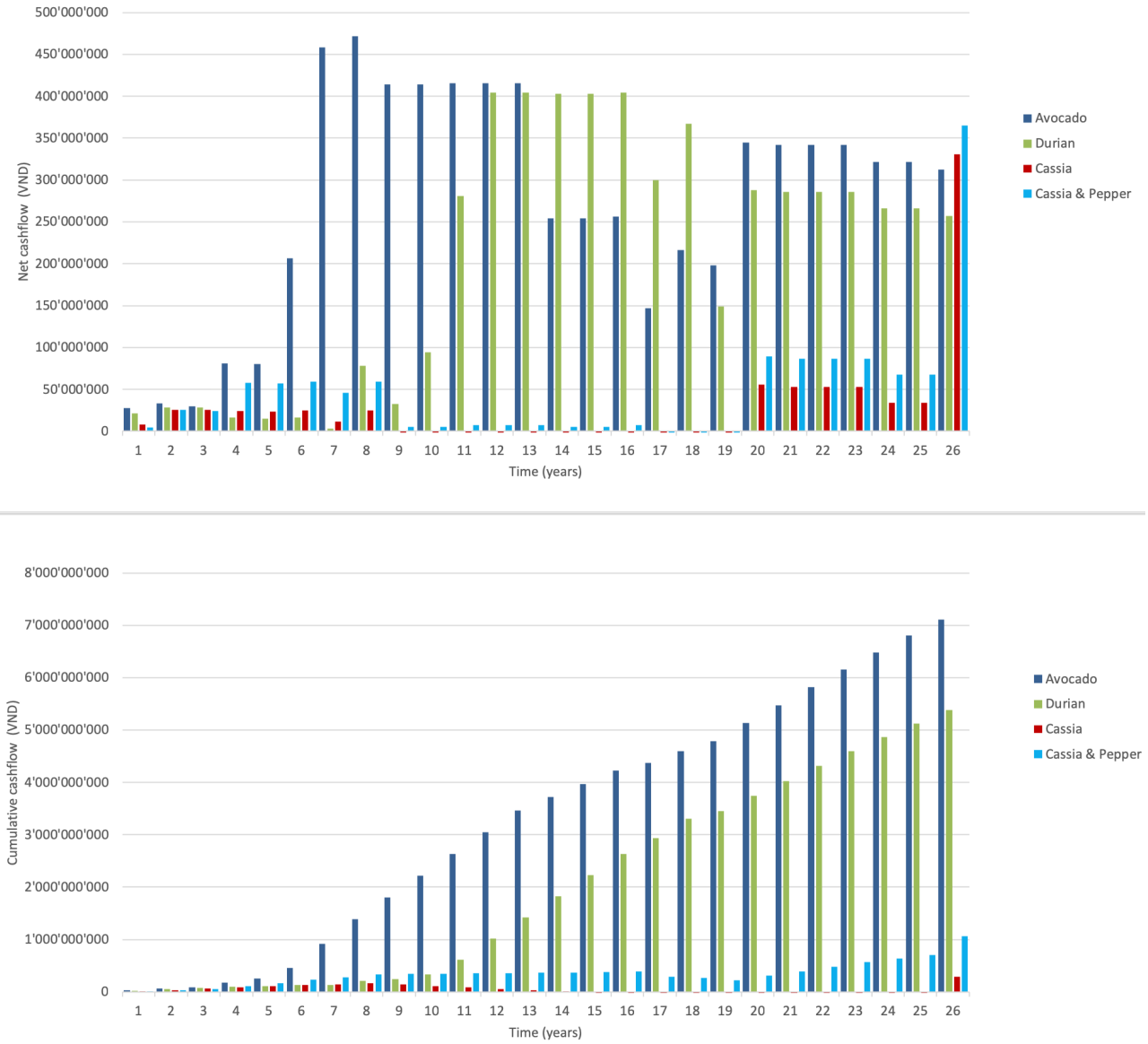
Model	Production System	Conversion Period	NPV (million VND)	IRR	Breakeven (years)
Conversion to intercropping	Coffee + Avocado	1 year	2'779	64%	6
Conversion to intercropping	Coffee + Avocado	5 years	2'345	48%	8
Conversion to intercropping	Coffee + Avocado	10 years	1'905	38%	7
Conversion to intercropping	Coffee + Durian	1 year	1'715	31%	9
Conversion to intercropping	Coffee + Durian	5 years	1'433	27%	10
Conversion to intercropping	Coffee + Durian	10 years	1'141	24%	11
Conversion to intercropping	Coffee, Cassia + Pepper	1 year	303	18%	9
Conversion to intercropping	Coffee, Cassia + Pepper	5 years	251	16%	9
Conversion to intercropping	Coffee, Cassia + Pepper	10 years	213	15%	10
Rejuvenation of coffee	Coffee	1 year	61	12%	8
Rejuvenation of coffee	Coffee	5 years	19	9%	12
Conversion to intercropping	Coffee + Cassia	10 years	5	8%	13
Conversion to intercropping	Coffee + Cassia	1 year	(10)	7%	14
Conversion to intercropping	Coffee + Cassia	5 years	(10)	7%	14
No rejuvenation	Coffee	No rejuvenation	(665)	0	n/a

**scenario that assumes observed 2016 farm-gate price of Robusta price = 40 million VND/tonne, Avocado = 51,000 VND/kg, Durian = 25,000 VND/kg, Pepper = 60,000 VND/kg and an initial age of the plantation = 23 years*

Projected cash flows for transitioning intercropping models

Figure 3 shows the annual cash flow profile for the different intercropping systems analysed over a 25-year cycle. For each of the intercropping crops, cash flows are delayed by a number of years until the plant is mature enough to become productive. Once it is productive, cash flows are determined by the frequency and size of harvest and the value of the crop. In this scenario, pepper has the highest market price per kilogram, but volumes produced per hectare were lower than avocado and durian, and the operational costs involved in cultivating pepper were higher than for other crops. Cassia siamea is harvested for timber in the final year which provides a significant cashflow. Models of coffee intercropped with forest trees, like Cassia siamea, however, prove less popular due to uncertainty about the economic value of such a model over longer time periods.

Figure 3: Net cashflow and cumulative cashflow profile over 25-years for Coffee-Avocado, Coffee-Durian, Coffee-Cassia and Coffee-Cassia/Pepper based on conversion over 1-year period (age of initial plantation 10 years, Robusta price = 40 million VND/tonne, Avocado = 51,000 VND/kg, Durian = 25,000 VND/kg, Pepper = 60,000 VND/kg).



Capital and operational costs of transitioning to intercropping

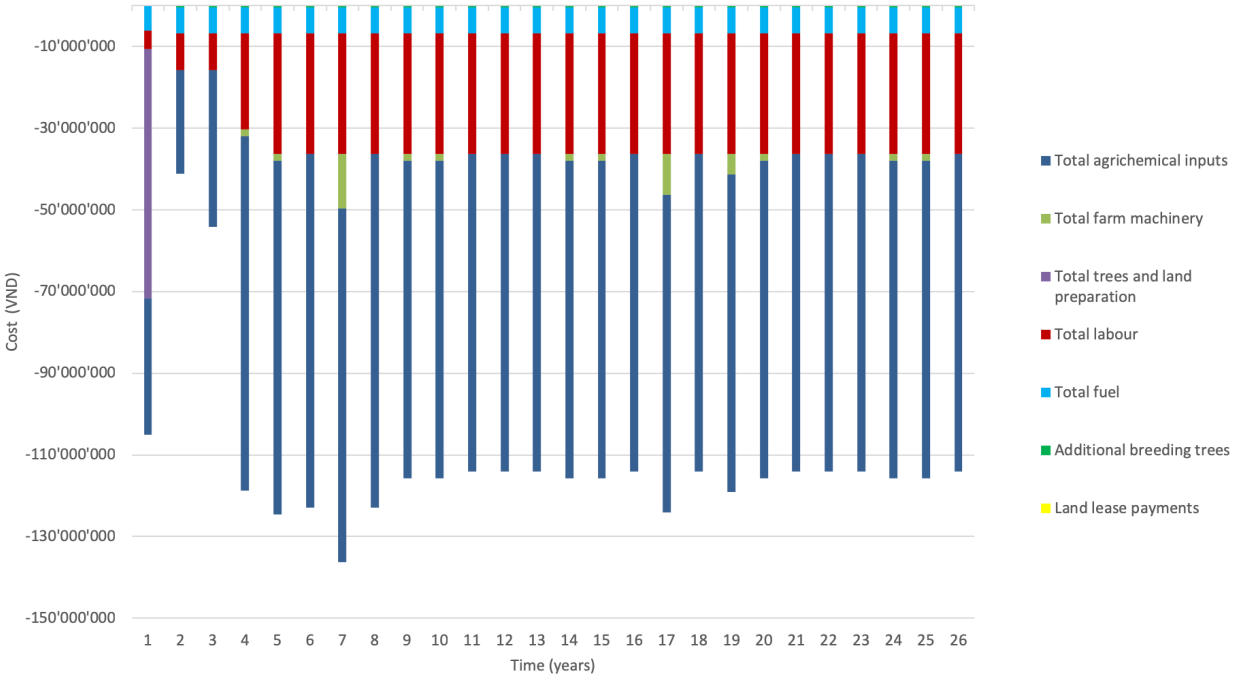
A number of investments need to be made for a smallholder to transition from a coffee mono-crop model to an intercropping model. These are mainly: cost of seedlings, cost of ground preparation, planting and labour. The most significant investment cost was the initial investment in labour for land preparation and planting. The investment cost therefore reflected the target density of the crop. Planting density was based on the results of field studies conducted by Nghia et al. (2016).[49] Cassia/pepper were planted at a higher density than durian, which was planted at 1 plant per 9m2 and avocado was planted as 1 plant per 12m^2.

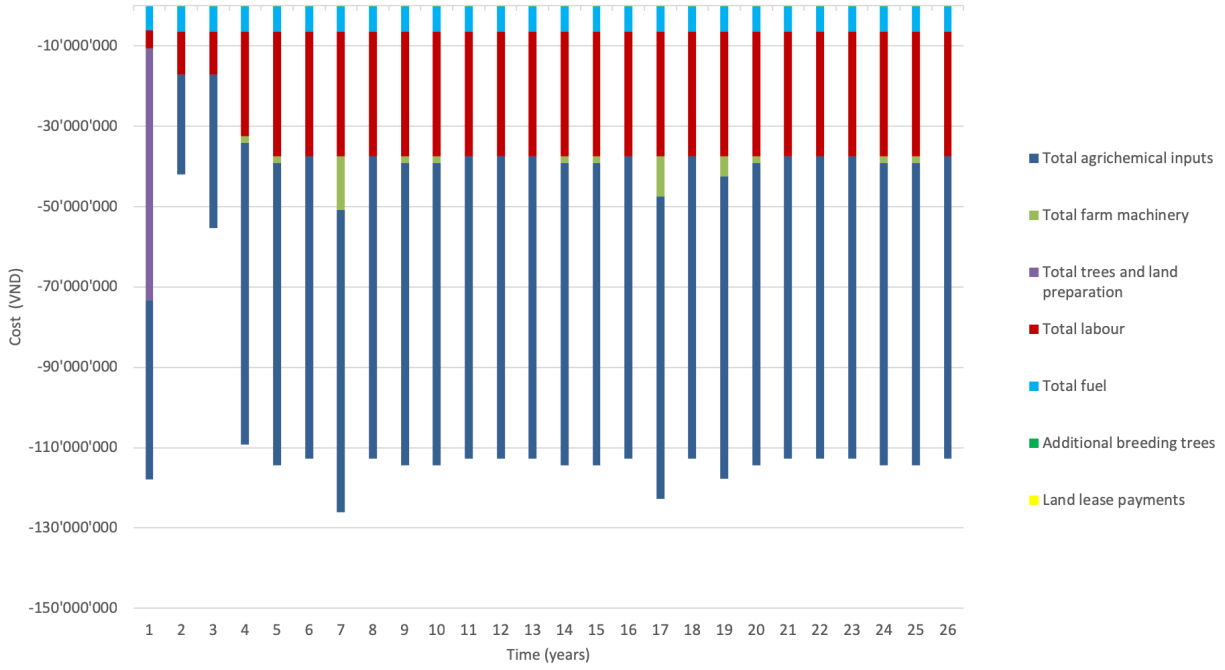
The capital expenditure involved was significantly more for the conversion to intercropping with durian and avocado than the additional operational expenditure. The opposite is true for the conversion to Cassia and Cassia with pepper, for which both capital and additional operational costs were higher.

The operational expenditure was mainly comprised of agricultural input for each of the scenarios modelled: pesticides, herbicides, synthetic fertilizers. The next largest cost is labour for weeding, watering, spraying, pruning and harvesting. The analysis was not able to account for the potential impact that possible co-benefits, such as those derived from inter-species synergies or improved farm-level biodiversity, would have on productivity or a resulting lower requirement for synthetic fertilizers and other agricultural input.

Figure 4 shows that that synthetic fertilizer is the largest single cost item in each of the production models analysed. The application of synthetic fertilizer can amount to as much as VND 70million /ha/ year. Based on the example provided by IFAD, this implies that there is considerable room for reducing the amount of fertilizer applied, without leading to a significant reduction in yield. Indeed, this analysis shows that even a modest reduction in fertilizer application of around 5-10% will lead to a large impact on the financial gains for the smallholder. For example, at coffee price of 32,000 VND/kg, reducing the amount of synthetic fertilizer applied by 10% will increase the NPV from -12 million, to 62 million VND, with an IRR of 13%, implying that the model is economically profitable, even at a 20% lower price for coffee.

Figure 4: Annual cost for one-year conversion to intercropping with durian (top) and Cassia with pepper (below).





Reducing the application of synthetic fertilizer and other input would not only reduce the cost of production of Robusta coffee, increasing the profit margins for smallholders, but it has also been reported to have a positive feedback effect on soil health and structure, which could in turn lead to further reductions in the need for agrichemical application and irrigation. The financial implications of this relationship and the potential impact of increasing biodiversity through intercropping has not been captured by this model. This will be the scope for a subsequent phase of development. Of particular interest is the cost implications of shade on coffee cultivation. It was widely reported that increased shade in coffee plantations has a negative impact on the quantity of cherries produced, but a positive impact on the quality. As quality is a key determinant of price, this would enable smallholders to achieve a higher price for their output.[50] This relationship will become more valuable as the impacts of climate change are felt over the coming decades.

The misalignment between cash flow streams and capital expenditure requirements means that conversion to an intercropping model may not be affordable for many smallholders. Table 3 shows the capital and additional operational expenditure required to convert a coffee smallholding to intercropping and the ratio of net income/capital expenditure.

The net income to capital expenditure ratio provides insight into the affordability of an investment. The negative ratios shown in Table 3 indicate that without savings or additional financing, it would not be possible for smallholders to generate sufficient capital to invest in the conversion to intercropping. However, as shown in the next section, by altering the conversion period, or initiating a conversion at a different point in the life cycle of a coffee plantation, it is possible to alter the annual capital requirement, or the net cashflow, potentially making a conversion more financially accessible for smallholders.

Impact of changing the conversion period for transitioning to intercropping

Increasing the conversion period from intensive mono-crop cultivations to intercropping will lead to a reduction in the NPV of the production system over a 25-year lifetime. A more rapid conversion introduces younger, more productive plants more quickly to the farm, which are able to compensate for the less productive coffee.

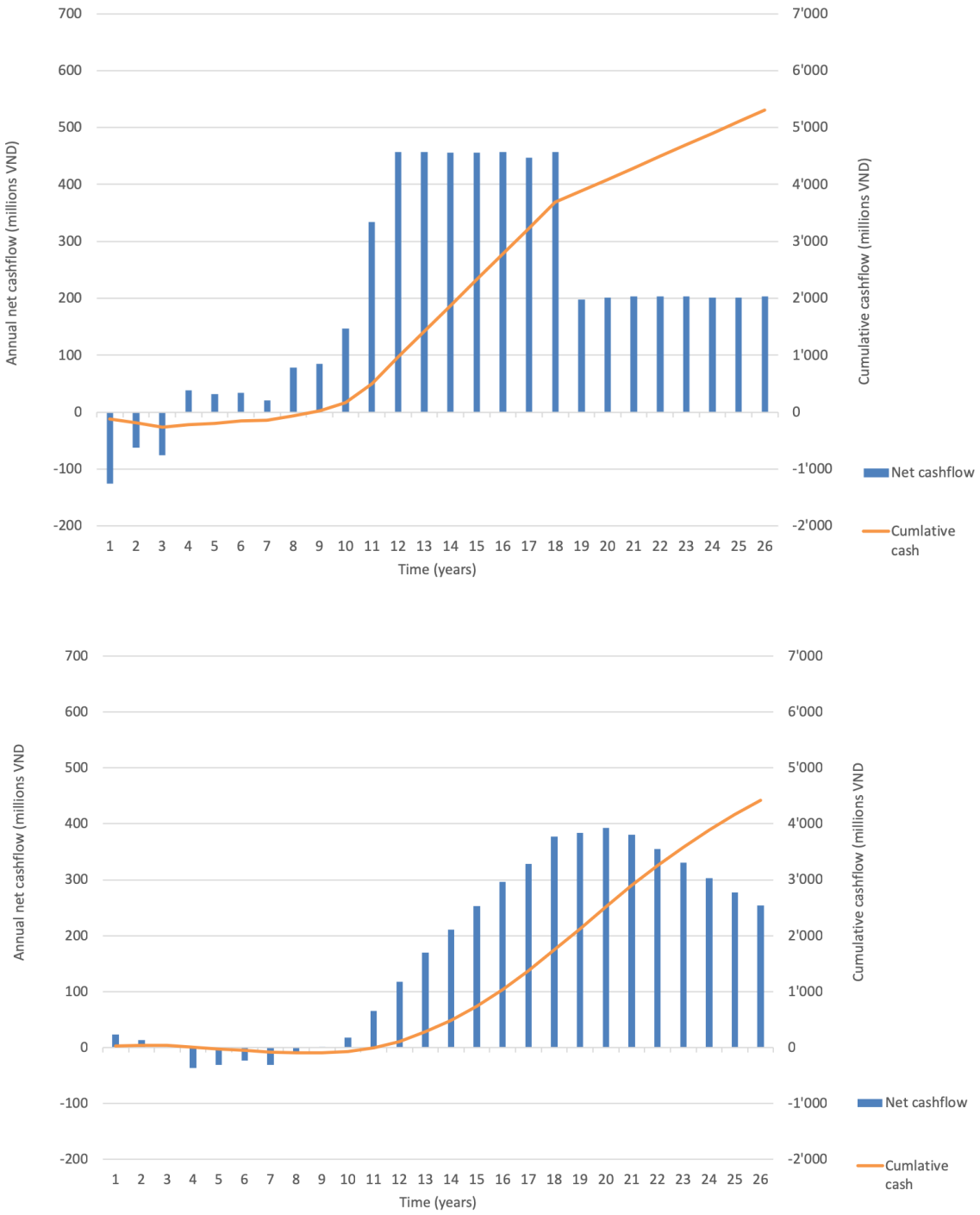
Table 3: Total capital and operational expenditure for conversion to intercropping models and the minimum coffee price necessary to achieve required free cash flow to self-finance the conversion for two plantations, 10 and 23 years old (price - thousands VND, Coffee price = thousands VND/tonne).

Intercropping crop	Initial capital expenditure ('000 VND)	Additional operational expenditure ('000 VND)	Total capital requirement ('000 VND)	Annual net income/Annual cap expenditure*
Durian	7'654	628	8'282	-0.39
Avocado	5'694	1'250	6'944	-0.36
Cassia	7'497	12'240	19'737	-0.26
Cassia with Pepper	10'857	12'240	23'097	-1.42

** at price of coffee of 1.72 USD/kg and an age of plantation of 23 years.*

While a rapid conversion is economically more beneficial for smallholders, however, the initial capital requirement is larger. This makes rapid conversions to intercropping less accessible for smallholders. Figure 5 shows the difference in net and cumulative cash flow for two scenarios: the first undergoing a rapid conversion to intercropping in one-year; the second, a slower conversion over a longer period of 10-years. All other conditions are the same.

Figure 5: Annual net cash flow and cumulative cash flow for a coffee monocrop system converting to intercropping: the left shows a system converting in one year, the right shows a system converting over 10 years (initial age of crop 15 years).



A longer conversion spreads the total capital expenditure over a longer period, making it more affordable for smallholders. This can be seen in Table 4, which compares the net income to capital expenditure ratios for conversions of different length.

Impact of initiating the conversion to intercropping on plantations of different ages

After an initial period of growth, coffee yields decrease over time, leading to a reduction in revenue for smallholders. The plantations of smallholders who initiate a conversion to intercropping later in the lifespan, will be less productive, and therefore provide less revenue. This is shown in Table 5, which compares the net income to capital expenditure ratio for a single year conversion to intercropping initiated at different stages in the coffee plantation lifespan. For each of the scenarios modelled, the ratio is the same for a conversion initiated at seven years as a conversion initiated at 14 years. This is consistent with the yield curve of coffee once it reaches maturity, before it begins to decline. As can be seen from Table 5, conversions in a younger plantation have no need for additional capital and can potentially be self-financed by the smallholder.

Table 4: Net income/ cap expenditure ratio for a 1-year, 5-year and 10-year conversion to intercropping or a 21-year old plantation.

Intercropping crop	1 year conversion	5 year conversion	10 year conversion
Avocado	-0.36	0.51	1.60
Durian	-0.39	0.18	0.89
Cassia	-0.26	-1.40	-0.57
Cassia with Pepper	-1.42	-0.97	-0.39

Table 5: Net income to cap expenditure ratio for a one-year conversion to intercropping for a 10-year, 15-year and 20-year old coffee plantation.

Intercropping crop	7 year old plantation	14 year old plantation	21 year old plantation
Avocado	9.52	9.52	-0.36
Durian	6.58	6.58	-0.39
Cassia	4.84	4.84	-2.06
Cassia with Pepper	3.34	3.34	-1.42

III. Economic resilience of solutions to the changing Robusta market conditions

Impact of diversification on resilience to changes in market price

So far, this analysis has assumed that prices would stay consistent with those observed by Dr Nghia and his team. While volatility is unlikely to reach the levels observed in the global market, in recent years both pepper and durian experienced periods of high prices, leading to over-supply and subsequent price drop. The Vietnamese Pepper Association reported that the price of pepper stood at its peak at VND 170,000 – VND 200,000 / kg before dropping to VND55,000-VND60,000 per kilogram in 2018 and again to VND41,000 per kilogram in 2019.[52] Similarly for durian, the recent high prices that reached VND60-70,000 eventually gave way to lower prices of VND30-40,000/kg.

Table 6: Performance of cultivation models as measured by NPV over 25 years ('million VND) PDF 2008-present based on inflation adjusted prices (sorted by highest NPV to lowest).

		NPV of model (millions VND) at coffee price percentile		
Model	Price percentile	25th	50th	75th
Durian	75th	5'992	6'357	6'962
Durian	50th	3'039	3'403	4'008
Avocado	75th	2'874	3'258	3'896
Avocado	50th	1'483	2'275	2'506
Durian	25th	1'283	1'647	2'252
Avocado	25th	873	1'257	2'180
Cassia & pepper	75th	70	424	1'010
Cassia & pepper	50th	(110)	244	830
Cassia & pepper	25th	(270)	84	671
Cassia	n/a	(492)	(139)	448
Coffee monocrop 1-year rejuvenation	n/a	(511)	(92)	604
Coffee monocrop 10-yr rejuvenation	n/a	(607)	(213)	440
Coffee monocrop no rejuvenation	n/a	(1'034)	(764)	(316)

** farm-gate prices are approximated by reducing market prices by 20%.*

Likelihood that the market price will be above the threshold to provide sustainable livelihood for smallholders

Table 7 shows the minimum price of coffee that will provide a sustainable livelihood for smallholders under different market conditions for the intercropping market[53] and the likelihood of that price being achieved. At the prices run in this scenario, intercropping models for coffee intercropped with durian or avocado would have provided a positive NPV over 25 years, even without the inclusion of the revenue generated from the sale of coffee.

Table 7: Minimum farm-price for coffee to provide a positive NPV over 25 years and likelihood of being over the minimum farm- gate price for different cultivation models.

Model	Minimum sustainable farm-gate coffee price (USD/kg)				Likelihood (farm-gate price>Pmin) real prices (2008-present)			
	2016 prices	25th percentile	50th percentile	75th percentile	2016 prices	25th percentile	50th percentile	75th percentile
Durian	0.00	0.00	0.00	0.00	100%	100%	100%	100%
Avocado	0.00	0.13	0.00	0.00	100%	99.9%	100%	100%
Cassia & pepper	1.35	1.46	1.26	1.04	73%	65%	74%	82%
Coffee monocrop 1-year rejuvenation	1.657	1.657	1.657	1.657	43%	43%	43%	43%
Cassia	1.74	1.74	1.74	1.74	38%	38%	38%	38%
Coffee monocrop 10-year rejuvenation	1.8	1.8	1.8	1.80	36%	36%	36%	36%

*(*Assumption is farm-gate price is 80% market price and initial age of plantation is 10-years.)*

Likelihood that intercropping systems can be self-financed through revenues from coffee

Initiating a conversion to intercropping at an earlier point in the plantation lifespan enables smallholders to benefit from higher positive cash flows, generated by younger and more productive crops. Smallholders are therefore more likely to generate sufficient cash flow for the capital and additional operational expenditure for a conversion to intercropping if they convert towards the beginning of the typical lifespan of a coffee plantation for (i) a 10-year old plantation and (ii) a 23-year old plantation.

Table 8: Total cap ex and op ex requirement for conversion to intercropping models and the minimum coffee price necessary to achieve sufficient required free cash flow for the capital expenditure and additional operational costs for conversion (prices VND).

Model	Capital expenditure	Operational expenditure yr. 1 (VND)	Total capital requirement yr. 1 (VND)	Farm-gate Pmin 10-yrs old (USD/kg)	P(price>Pmin) (2008-present)	Farm-gate min price 23-yrs old (USD/kg)	P(price>Pmin) (2008-present)
Durian	7'654'321	627'778	8'282'099	1.27	73.5%	1.89	34.6%
Avocado	5'694'444	1'250'000	6'944'444	1.23	73.5%	1.84	36.0%
Cassia	7'497'000	12'240'000	19'737'000	1.40	68.4%	2.10	30.1%
Cassia & Pepper	10'857'000	12'240'000	23'097'000	1.44	66.2%	2.16	26.5%

6. Discussion of risk factors

Due to their low volumes, smallholders are price takers and vulnerable to unfair pricing practices

Smallholders commonly sell their produce immediately, or within two to three months after harvest, because farmers need immediate cash for daily living and because typically, they do not have the facilities needed to store their harvested products for long periods. Farmers are highly dependent on local collectors due to their distance from markets. This allows collectors to manipulate prices and there is no mechanism that can control the fairness of prices offered by collectors.[54]

Smallholder technical capacity is low, leaving them vulnerable to the impact of disease and increasing phytosanitary standards from importing countries

Low levels of technical capacity, combined with a lack of compliance with technical and health safety standards lead to an increase in the incidence of pests and diseases, which could compromise the quality of produce and leave smallholders exposed to more stringent import standards from key markets.[55]

For example, high pepper prices in recent years led to the rapid development of pepper production in the Central Highlands, reducing the area under coffee cultivation and expanding pepper onto unsuitable land.[56] This combined with the low technical capacity of smallholders meant that much of the pepper produced was found not to conform to European and Japanese phytosanitary standards, which could lead to an import ban by the two markets.

Chinese imports are a key driver for durian price and production in Vietnam.[57] In early 2019, China increased its technical and phytosanitary standards, as well as regulations on food safety. In order to comply with these more stringent standards, producers from Vietnam will face an additional production costs.

There are a number of barriers which could limit the success of avocado cultivation that have not yet been captured in this analysis and which may slow the conversion to avocado cultivation. These include unreliable yields and deteriorating quality over time, which results from poor quality seedlings and a low capacity for cultivation.

Price risk for intercropping fruits is difficult to estimate

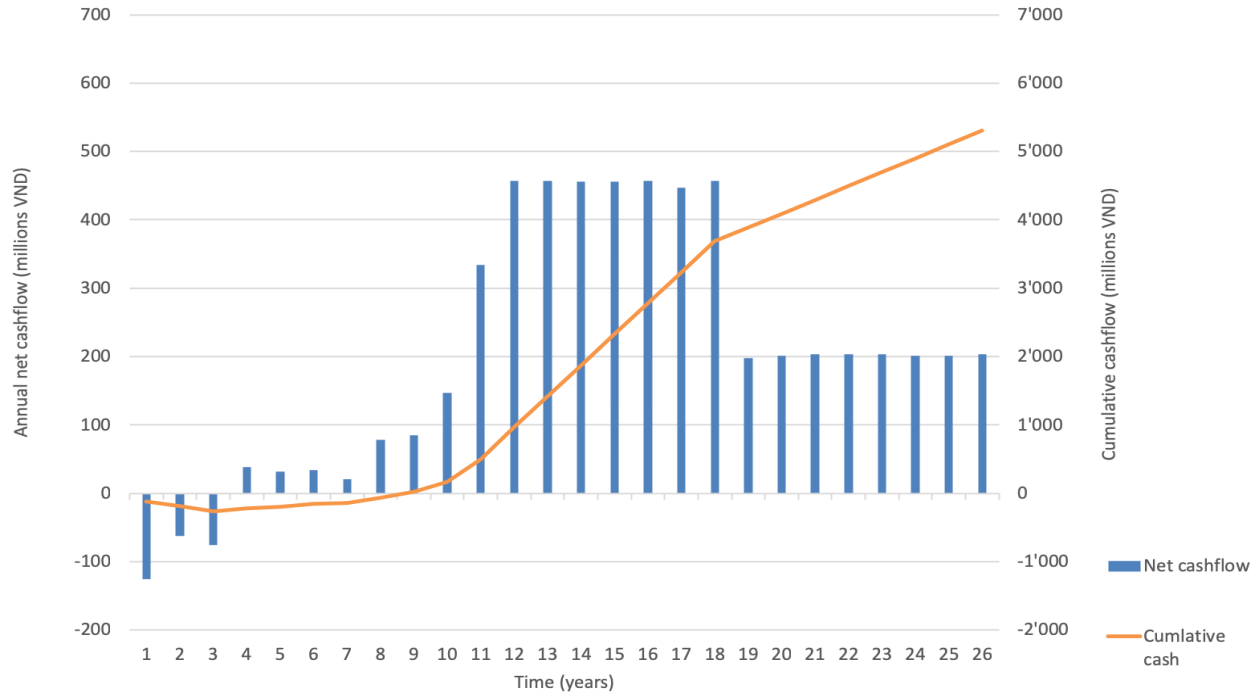
Data on farm-gate prices for non-coffee commodities is unreliable; prices are unregulated and information asymmetry is considerable, meaning farmers have low price visibility. As a result, it is possible that the farm-gate price will vary by location and the relationship that the farmer has with local aggregators.[58] This combined with market uncertainty and price volatility could make it difficult for farmers to estimate expected returns and make reliable market plans.

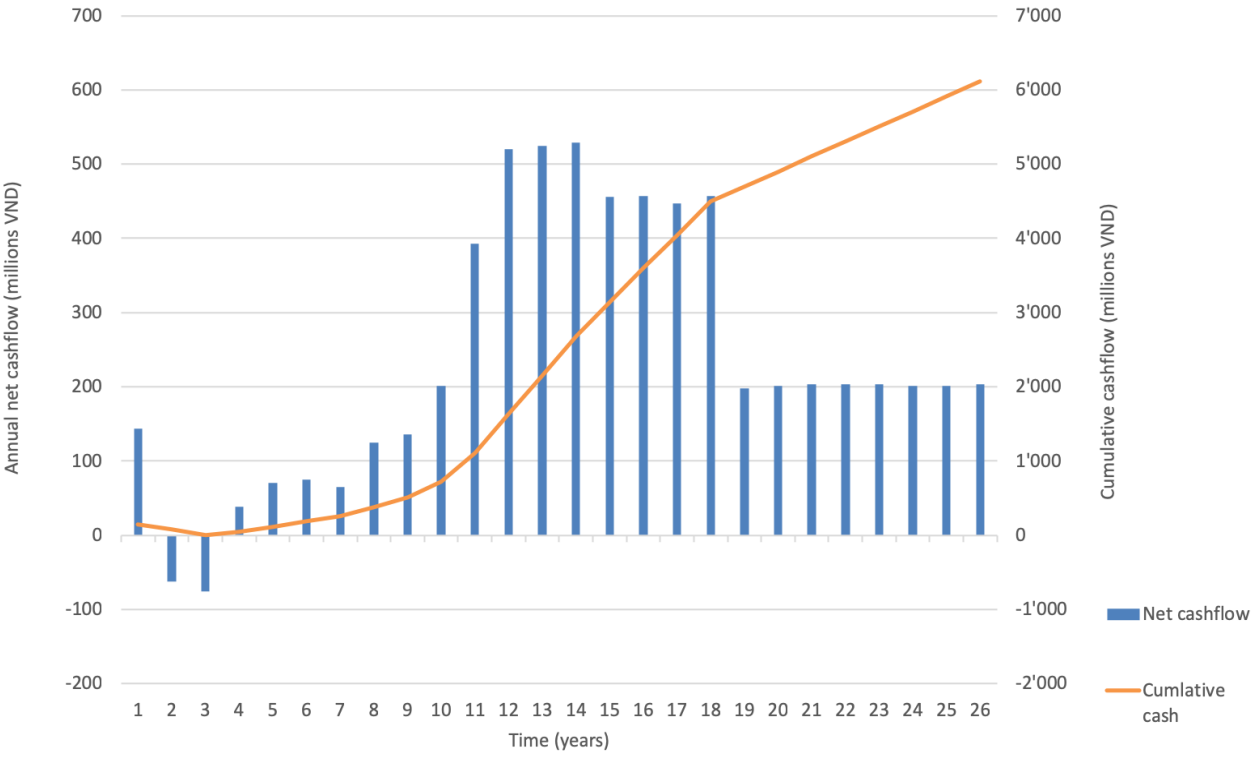
Income gap could be prohibitive to smallholders

The introduction of intercropping to a coffee plantation provides substantial economic gains when compared with a coffee-monocrop, however, positive returns are not realized until after the replanting phase, leading to a substantial income gap for smallholders. During these initial years the smallholder would have lower income from their planation and still face substantial capital expenditures associated with the conversion (purchase of seedlings, land preparation and planting, etc.), and ongoing operational expenditures, primarily comprised of agricultural input for the subsequent years.

The substantial cash flow gap experienced between replantation and first production may make the introduction of intercropping inaccessible for poorer households without access to additional financing for both the initial capital expenditure and additional working capital finance to support the operational expenditure. The left-hand side of Figure 6 shows the annual net and cumulative cash flow for a single year conversion to intercropping with durian. The initial capital expenditure and operational expenditure, combined with the delay in revenue from durian means that a smallholder who made this investment would not break even or be cash positive until the eighth year after the investment. During this time, a smallholder would need to generate additional income to support their livelihood, and this could increase the risk that a smallholder would expand into the forest in order to sell timber or grow faster maturing crops.

Figure 6: An example of annual net cash flow and cumulative cash flow for conversion to intercropping with durian from a 23-year old coffee plantation (left); the right shows the same situation, but financed with a loan of VND 270 million at an interest rate of 7.5% repaid over 10 years with a grace period of 3 years.





The right-hand side of Figure 6 shows the annual net and cumulative cash flow for the same scenario but financed with a loan, in this case for VND 270 million. The loan is sufficient to prevent the smallholder from requiring additional sources of income in order to support a livelihood, which will increase the long-term sustainability of the conversion and reduce further pressure on the remaining forests in the region.

Table 9: Loan repayment schedule for VND 270 million at an interest rate of 7.5% repaid over 10 years with a grace period of 3 years.

Year	Opening loan Balance	Monthly Payment	Interest payment	Repayment of principle	Closing loan balance
4	270'000'000	39'335'200	20'250'000	19'085'200	250'914'800
5	250'914'800	39'335'200	18'818'610	20'516'590	230'398'209
6	230'398'209	39'335'200	17'279'866	22'055'335	208'342'874
7	208'342'874	39'335'200	15'625'716	23'709'485	184'633'390
8	184'633'390	39'335'200	13'847'504	25'487'696	159'145'693
9	159'145'693	39'335'200	11'935'927	27'399'273	131'746'420
10	131'746'420	39'335'200	9'880'982	29'454'219	102'292'201
11	102,292,201	39,335,200	7,671,915	31,663,285	70,628,916
12	70,628,916	39,335,200	5,297,169	34,038,032	36,590,884
13	36,590,884	39,335,200	2,744,316	36,590,884	0

Inadequate financial coverage is a constraint facing farmers during the growing season

A lack of investment and poor access to agricultural credit are key obstacles to increasing productivity and production quality by introducing new varieties and applying enhanced technologies and innovations.[59] Many small farmers lack financial resources to reinvest in crops.[60] The strict collateral and procedural requirements in order to obtain a loan from a formal financial institution, and the constant working capital needs of coffee farmers, have led to the emergence of an informal credit market, provided by small-scale traders and collection agents that operate at the commune level. Many smallholders borrow money to spend in January and repay the loan when they finish harvesting coffee from October to December.

The requirement for training and implementation support

A large proportion of the success of a model is determined by the level of training a smallholder receives in the technical aspects of implementation. This includes soil testing and management, pest management, irrigation and knowledge of the appropriate time and levels of application for inputs. In order for intercropping to become successful in the Central Highlands, smallholders would benefit greatly from effective training. However, the form this training should take falls outside the scope of this brief.

7. Conclusion and recommendations

Coffee production in the Central Highlands faces a multitude of challenges. Decades of intensive cultivation and expansion onto marginal land has left smallholders less resilient to both climate change and market risk. Many smallholders are in a negative spiral of declining yields and increasing application of inputs leading to lower margins. In order to sure up the sector, interventions should focus on models that place environmental sustainability and resilient livelihoods at their core.

Even in poor market conditions, diversifying a smallholding through the addition of another productive crop will generate economic benefits. Furthermore, the revenue generated through the addition of a crop can help to reduce the impact of periods of low coffee price on a smallholder's livelihood. However, while this will provide a degree of economic resilience to a smallholder, if the coffee price remains consistently subdued, it cannot be said that the smallholder will or should not make the economically rational decision to replace their coffee plantation with what they perceive to be a more lucrative or less volatile crop.

In addition to economic benefits, diversifying a smallholding can bring potential environmental benefits, leading to increased biodiversity and improved soil structure, that may further contribute to the economic profitability of the model by reducing the requirement for irrigation or agricultural inputs. In each of the models analysed, agricultural inputs made up the largest portion of the costs for a smallholder, even a small reduction in their application would have a noticeable impact on smallholder margins while further contributing to biodiversity improvements and helping increase resilience.

Transitioning to an intercropping model requires capital expenditure and increased operational expenditure. For poorer households, transitioning to a diversified model such as intercropping may be financially inaccessible without access to additional financing. It will be more affordable if the transition is initiated in a younger, more productive coffee plantation, than an older less productive plantation. Additionally, the financial burden can be reduced by staggering the introduction over a multi-year period.

Accessibility of a model to poorer households is also determined by the length of the transition period until the crop reaches productivity. Where the crop matures more quickly, this will make it more accessible to farmer cultivation by reducing the transition period. This makes crops with a lower transition period more accessible, however it does not necessarily reflect the overall productivity of the model.

The comparative profitability of any intercropping model will be determined by the ratio of the additional capital and operational expenditure to the yield and farm gate price for each crop. This study has conducted a rudimentary assessment of each of the model's resilience to changes in the price of coffee. To fully understand each of the model's resilience to changing environmental and macroeconomic conditions, further work is required to understand the short and long-term trends and drivers for the costs of inputs and farm gate prices. For example, irrigation is presently free for smallholders across the Central Highlands, but the availability of water for irrigation could be a severe restriction in the mid-term. Similarly, recent socio-economic trends have seen a decline in the availability, and an according increase in the cost, of labour, which will also impact the economic resilience of smallholder production. Finally, a large proportion of the likelihood of success for a novel cultivation model is determined by the level of training and support received by a smallholder. Support in the form of training is vital for smallholders, otherwise, it would be all to easy for them to revert back to practices that they are more comfortable with.

Appendix I: Results of market capacity analysis

Fruit	global market	domestic market conditions		Market Barriers	Drivers and Established routes to market	Suitable for Intercropping
	Outlook	Export and Production:	Outlook			
Banana				As banana is one of the most common fruits in Vietnam, it is assumed that there is no need for improvement. Currently, there is no cultivar grown commercially for export, and there is no breeding program in any of the fruit research institutes.		No
Mangosteen		Tran Van Vien, owner of the An Son Agricultural Service Cooperative, said the province had promoted exports of mangosteen from An Son commune to China, but there are no mangosteens left for export.		takes a very long time for trees to bear fruit, strict import criteria for a lot of countries (fear of fruit fly)	high, stable prices, high market demand, government subsidies for fertilizer	N/A
Jackfruit				Breadfruit is still a minor crop in Vietnam. There is currently no varietal improvement, resulting in poor yield. There is very limited market for the fruit harvested.		No
Persimmon				The biggest problems in commercial-scale cultivation in Vietnam are the lack of existing technology, especially suitable cultivars to be grown in specific zones, and the lack of experience in post-harvest technology, transportation and marketing.		No
Pepper	Pepper prices are on a correction mode having touched a ten-year low recently. Global pepper production is also estimated to fall in 2019. Pepper prices are likely to firm up only by 2020 when demand catches up with the supply.	Dak Lak is currently the largest production region (23% of total), showing a CAGR of 21% since 2012. Vietnam now exports 95% of its annual pepper produced. It exports to 109 countries and territories, mainly to Europe, Asia and America.	Global demand is estimated to increase by 2 percent annually, while supply is growing by 8-10 percent, according to the IPC.. With this imbalance, the fall in prices in recent years was inevitable.	technical barrier of importing countries (such as low chemical residue); quality of pepper in global markets, oversupply		Yes
Macadamia	The global macadamia supply for 2015 was 170 000t NIS, up 30% from 2012's 130 000t. Worldwide plantings are rising rapidly and the industry has predicted a 500 000t crop by 2022.	Through VMA's survey basing on the supplied seeds to farmers in 2016, the country will plant 1.4 macadamia tree in over 3,500 hectare. Many farmers planted the tree and coffee in the same land and have good harvest.	General Secretary of VMA Huynh Ngoc Huy said that in its plan, VMA will plant 30 million macadamia trees in the Southeast Asian country within the next ten years producing 350,000-400,000 tons earning around $1 billion. It will build 38 state-of-the-art processing factories in the highlands and the northwest region in Vietnam.	Limited processing capacity	Increasing demand	Yes
Avocado	Growing interest in the western world, production continues to grow, promotional campaigns across the globe	Mostly local consumption	Vietnam is seeking to export avocados to the United States after U.S. President Donald Trump's threat to shut the U.S.-Mexico border raised fears American consumers could see a shortage	Export from Vietnam to China to face strict controls on labelling, packaging and information as well as a tightening of import procedures at border gates.	Avocados leave Dak Lak either through the wholesalers in Buon Ma Thuot or through the district wholesalers.	Yes
Durian	Total trade for durian fruit is expected to grow from approximately 1.5 billion KG in 2016 to over 2.7 billion KG by 2030, according to the estimation of Plantations International.	In Vietnam, durians ares mainly cultivated in the South but there are some orchardsin the highlands in Lam Dong province at elevation of about 600 to 1000 mm. In 2017, Vietnam became a key importer of durian and 80%-85% of the imported durians are re-exported to China.	The demand from China has been growing but there is increasing regulation requirement for import of durian. Early 2019, China increased its technical and phytosanitary standards, as well as regulations on food safety. In order to meet these standards, producers from Vietnam are facing a higher cost.	poor quality due to the lack of good cultivars	demand and trade regulation in China	Yes
Dragon Fruit	Dragon Fruit enjoyed smooth sales but the price is not expected to increase significantly.	Dragon fruit is a Vietnamese agricultural staple, with export earnings of 895.7 million USD in 2016, making up of 50.3 percent of the country's fresh fruit exports and 36.1 percent of overall vegetable exports	The fruit is also entering new markets including India, New Zealand, Australia and Chile	Lack of fruit trademark, very short shelf life, quality problems, small scale production,	Vietnamese dragon fruit has been exported to 40 countries and territories such as China, Thailand and Indonesia.	N/A
Cassava	Combination of policy changes, climate change and low root prices.	Large decline of production, shortfall of approximately 6.7 million tonnes	Decreased demand due to US-China trade war, and stockpile price adjustment from Vietnamese plants	Exporters from Vietnam to China face strict controls on labelling, packaging and information as well as a tightening of import procedures at border gates	high demand, low quantities	yes
Cashew	Decreasing cashew prices	exported close to 260,000 tonnes of cashews worth 2050 million U.S. dollars in the first nine months of 2016	Decreasing cashew prices	Quality problems	Well established, expanding business opportunities, improved domestic supply	yes

Appendix II

Model assumptions

Assumptions of the yield curve and input regimes of different crops, as well as other costs and revenues, were provided from primary data generated by the Institute for Policy and Strategy for Agricultural and Rural Development (IPSARD) and the United Nations Development Programme (NDP). It was published in the report 'Formulation of priority policies and measures for sustainable coffee and aquaculture supply chains' (Nghia et al. 2016).[61] The assumptions on costs and revenues were additionally reviewed by the Western Highlands Agriculture & Forestry Science Institute (WASI) and the International Centre for Tropical Agriculture (CIAT).

Land area

The calculations involved in this study assume a smallholding of 1 ha in area.

Crop density

This study assumes that a smallholder plants a new crop of coffee at a density of 3m x 3m, which is equivalent to 1,111 trees/ha.

In intercropping plantations, it is assumed that the density of coffee plants is reduced in order to provide space for the intercropping plant. The density of planting for durians is 9x9m, the equivalent of 123 trees/ha. For avocado, the density is 12x12m, the equivalent to 69 trees/ha. For pepper and Cassia, Cassia is planted at 153 trees/ha.

Yield curves

In the Central Highlands, coffee typically has a useful lifespan of 25 years, after which the yield declines steadily. Coffee reaches the highest yield at 5 tonnes/ha from the fourth year to the seventh year, which is reduced to 4.5 tonnes/ha from the eighth year to the eighteenth year, and down to 3 tonnes/ha from the nineteenth year to the twenty-fifth year.

Durian bears fruit from seventh year, on average the tree can reach 10 fruits/tree, before increasing to 20 fruits/tree in the eighth year and increasing again to 50 fruits/tree in the ninth year. The maximum yield with 70 fruits/tree, is achieved between the tenth and eighteenth years, after which the yield drops to 50 fruits/tree.

Avocado bears fruit from the third year, producing around 15kg of fruit per tree for the third and fourth years, increasing to 50kg/tree in the fifth year. Between the sixth and twelfth year the tree produces 125kg/tree, before decreasing to 80kg/tree between the thirteenth and twenty-fifth year.[62]

Firewood is harvested from Cassia trees from the ninth year. From the ninth year until the sixteenth year, the amount of firewood harvested is around 330VND/tree. After the sixteenth year, this figure doubles to around 650VND/tree. In year 25, Cassia is harvested for timber, generating around 2million VND/tree.

Pepper produces 4kg/plant from the fourth year. It is assumed that this yield is stable over the lifespan of the plant.

To increase the accuracy of the model, further work is needed to identify key relationships within the model pertaining to input and productivity, as well as the impact of the long-term excessive application of input.

Table 10: Coffee yields for intensive, mono-crop coffee cultivation.

Period (years)	Coffee yield (tonnes/ha)
0-2	0
3-6	5
7-9	4.5
10-17	4.5
18-25	3

Table 11: Durian yield curve.

Period (years)	Durian yield (No. Durian/tree)	Mass per durian (kg)
0-6	0	0
7-8	10	2
9	20	2
10	50	2
11-17	70	2
18-25	50	1.5

Table 12: Avocado yield curve.

Period (years)	Avocado (kg/tree)
0-2	0
3-4	15
5	50
6-12	125
13-25	80

Table 13: Pepper yield.

Period (years)	Pepper (kg/tree)
4 onwards	4

Table 14: Cassia siamea.

Period (years)	Yield (VND/tree)
Fuel wood years 9-16	330
Fuel wood years 7-24	650
Timber year 25	2,000,000

Variable costs

a. Coffee and intercropping crop prices

In the absence of more accurate farm-gate data for smallholders, the initial prices used in this study are those proposed by Dr Nghia and his team. Coffee: 40,000 VND/kg, Durian: 25,000VND/kg. Avocado price is reported to be cyclical and varies throughout the years: Price: January–April: 50,000 VND/kg; May–July: 30,000–35,000 VND/kg; August–October: VND 65,000–70,000 VND/kg. To take this variation into account the avocado price is the arithmetic mean of the monthly prices, which is 51,000VND/kg.

Analysis is non-path dependent for 25-year period.

b. Cost of land preparation and planting

The calculations involved in this study assume a smallholding of area 1 ha.

This study assumes that a smallholder plants a new crop of coffee at a density of 3m x 3m, which is equivalent to 1,111 trees/ha.

In intercropping plantations, it is assumed that the density of coffee plants is reduced in order to provide space for the intercropping plant. This is a conservative estimate. The density of planting for durian is 9x9m, the equivalent of 123 trees/ha. For avocado, the density is 12x12m, the equivalent to 69 trees/ha. For pepper and Cassia, Cassia is planted at 153 trees/ha.

Table 15: Land preparation and planting costs.

Plant	Coffee (mono-crop)	Avocado	Durian	Cassia Siamea	Pepper
Cost of plant (VND)	7000	35,000	15,000	2000	20,000
Planting density (plants/ha)	1111	69	123	153	153
Cost of land preparation	30,000,000	30,000,000	30,000,000	30,000,000	30,000,000
Cost of planting	20,000	20,000	20,000	20,000	20,000
Annual replacement rate	1%	5 trees	5 trees	5 trees	n/a
Annual replacement rate	1%	5 trees	5 trees	5 trees	n/a

c. Input regimes

Input regimes were calculated from data averaged over three households. Additional input on the volume and price of input was provided by the Western Highlands Agriculture and Forestry Science Institute (WASI) and the International Centre for Tropical Agriculture (CIAT).

Table 16: Fertilizer costs.

Fertilizer	Cost	Unit
Lime	2,500	VND/kg
Organic fertilizer	4,000	VND/kg
Coffee husks	500	VND/tonne
Probiotics	77,000	VND/kg
Urea	8,7000	VND/kg
Sugar	16,600	VND/kg
Calcium Phosphate	3,600	VND/kg
Lime	2,500	VND/kg
Manure	2,400	VND/kg
KCL	120,000	VND/kg
NPK	12,000	VND/kg
SA	3,700	VND/kg

Table 17: Fertilizer application regime for coffee.

Year	Function	Fertilizer	Application regime
1		Lime	0.5 kg/tree/year
		Organic fertiliser	5.0kg/tree/year
		Calcium phosphate	0.4/kg/tree
		Urea	0.1kg/tree
		KCL	0.05kg/tree
2	Organic fertilizer production	Coffee husks	1 tonne/ha/year
		Probiotics	2 kg/ha
		Urea	10 kg/ha
		Sugar	1 kg/ha
		Calcium phosphate	50 kg/ha
		Lime	20 kg/ha
		Manure	200 kg/ha
		Calcium phosphate	0.5 kg/tree
		Urea	0.2kg/tree
		KCL	0.1kg/tree
		SA	0.1kg/tree
3	Organic fertilizer production	Coffee husks	1 tonne/ha/year
		Probiotics	2 kg/ha
		Urea	10 kg/ha
		Sugar	1 kg/ha
		Calcium phosphate	50 kg/ha
		Lime	20 kg/ha
		Manure	200 kg/ha
		Calcium phosphate	0.5 kg/tree
		Urea	0.3kg/tree
		KCL	0.2kg/tree
		SA	0.2kg/tree
4+	Organic fertilizer production	Coffee husks	1 tonne/ha/year
		Probiotics	2 kg/ha
		Urea	10 kg/ha
		Sugar	1 kg/ha
		Calcium phosphate	50 kg/ha
		Lime	20 kg/ha
		Manure	200 kg/ha
		Calcium phosphate	0.7 kg/tree
		Urea	0.5kg/tree
		KCL	0.5kg/tree
		SA	0.2kg/tree

Table 18: Fertilizer application regime for avocado.

Year	Fertilizer	Application regime
1	NPK	0.1 kg/tree/year
2	NPK	0.3 kg/tree/year
3	NPK	1.0 kg/tree/year
	Urea	0.5 kg/tree/year
4+	NPK	1.0 kg/tree/year
	Urea	0.5 kg/tree/year

Table 19: Fertilizer application regime for durian.

Year	Fertilizer	Application regime
1	NPK	0.1 kg/tree/year
	Urea	0.1 kg/tree/year
	Calcium phos-phate	0.5 kg/tree/year
2	NPK	0.4 kg/tree/year
	Urea	0.1 kg/tree/year
3	NPK	0.4 kg/tree/year
	Urea	0.1 kg/tree/year
4-7	Calcium phos-phate	1.2 kg/tree/year
	KCL	0.7 kg/tree/year
	Urea	0.1 kg/tree/year
7+	Red K	1.5 kg/tree /year
	Urea	0.5 kg/tree /year

Table 20: Fertilizer application for Cassia siamea.

Year	Fertilizer	Application regime
All	Organic fertilizer	20.0 kg/tree/year

Table 21: Fertilizer application for pepper.

Year	Fertilizer	Application regime
2+	Foliar	10,800 VND/tree

Table 22: Herbicide application for all crops.

All years	Herbicide	400,000 VND/ application/year
No. applications	2	

d. Labour requirements and costs

Table 23: Labour requirements for all crops.

Activity	Frequency	No. labourer /ha	Cost per labourer (VND)
Weeding	4	8	150,000
Watering	3.5	2	300,000
Spraying	3	4	200,000
Harvesting	1	70	150,000

Table 24: Pruning costs for coffee plants.

Year	Cost/tree (VND)
1-3	3500
4+	8000

Table 25: Coffee processing costs.

Year	Activity	Cost/tree (VND)
4+	Drying, grinding, seasoning	4000

e. Transport and fuel costs

Table 26: Fuel and transport cost for smallholders.

Substance	Volume consumed per year	Cost
Oil	400 litres/ha	11,000 VND/ litre
Gasoline	100 litres/ha	17,000 VND/ litre
Petroleum jelly	2 litres/ha	80,000 VND/ litre

f. Machinery and other fixed assets

It is assumed that fixed asset costs involve replacement costs only.

It is also assumed that fixed asset ownership is shared across multiple farms, as it does not make economic sense for one smallholder to have complete ownership of a machine.

Table 27: Economic lifespan and replacement costs for fam machinery.

Machine	Useful lifetime (yrs.)	Replacement cost (VND)
Water pump	12	10,000,000
Weeding machine	7	2,000,000
Farm vehicle	10	30,000,000
Watering system	5	5,000,000
Drying facilities	30	50,000,000
Lawn mower	10	40,000,000
Other facilities	5	5,000,0000

g. Yields

Table 28: Coffee yield from coffee monocrop.

Year	Yield (tonnes/ha)
4-7	5
8-18	4.5
18-25	3

Table 29: Avocado yield.

Year	Yield (kg/tree)
3-4	15
5	50
6-12	125
13-25	80

Table 30: Durian yield.

Year	Yield (no. durian/ tree)	Mass/durian
7-8	10	2
9	20	2
10	50	2
11-17	70	2
18-25	50	1.5

Table 31: Fuelwood and timber yield from Cassia siamea.

Year	Yield (VND/tree)
Fuel wood years 9-16	330
Fuel wood years 17-24	650
Timber	2,000,000

Table 32: Pepper yield.

Year	Yield (kg/tree)
4+	4

h. Discount rate

The discount rate adopted for these analyses is 7.5%, which is the interest rate charged by financial institutions on the cost of Vietnam Bank for Agriculture and Rural Development's agricultural loan offered to smallholders for rejuvenation. This is below the typical commercially offered interest rate.

i. Living costs[63]

Living cost per person: VND 295,350.
Average household size for Central Highlands: 5.92.

Appendix III: Calculation of price elasticities of demand

$$\Delta E[y \mid x] \approx \beta 1 \Delta \log e(x) \leftrightarrow \Delta E[y \mid x] \approx \beta 1/100\% \Delta x$$

Commodity	Beta0	Beta1	Price Elasticity (PEx)
Avocado	9.34616107799376	−0.575457422072315	−0.478941892301668
Durian	10.5033576222948	−0.660826705609437	−0.448102229077449
Macadamia	21.9556825404505	−1.32355098472666	−0.500969251680293
Pepper	13.227836405629	−0.551066882043441	−0.351455096920998
Cassava	3.36186049184345	−0.17784736246988	−0.0819826616147934
Cashew	13.5539724393367	−0.696344575363749	−0.608149353286838
Coffee	16.7180502088775	−0.962151670691781	−0.38702677397884

For each commodity, the price elasticity is relatively inelastic, PE = ($0 < |PEx| < 1$).

Figure 8: Demand curve for avocado based on trade data where Vietnam was the originating partner

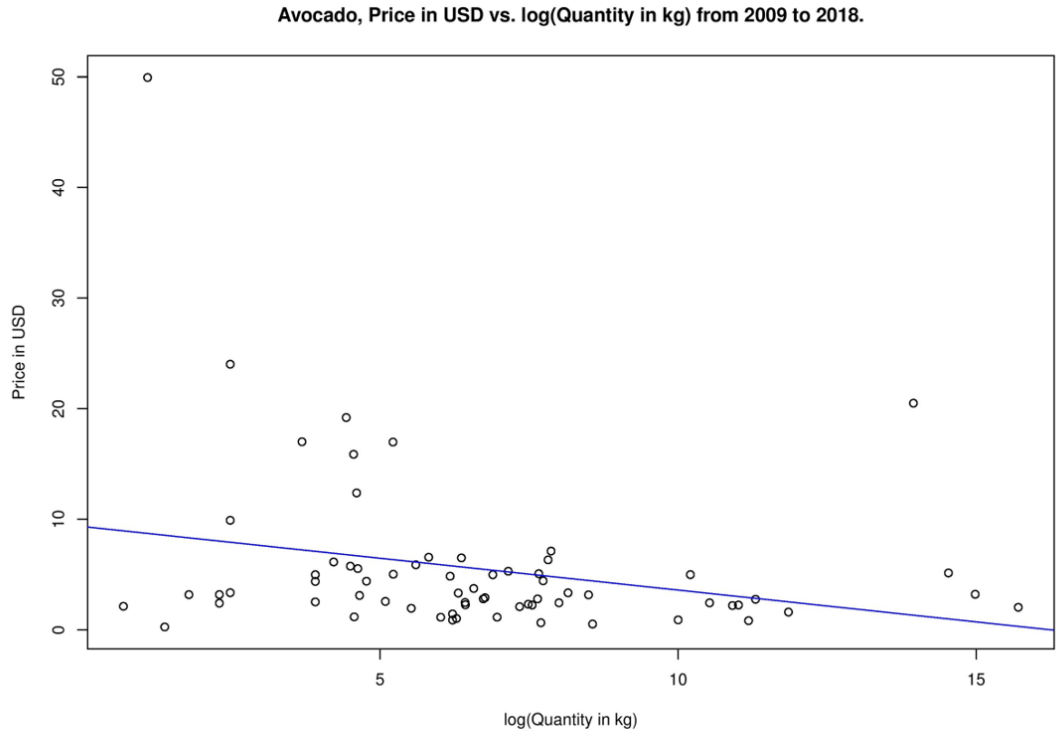


Figure 9: Demand curve for durian based on trade data where Vietnam was the originating partner.

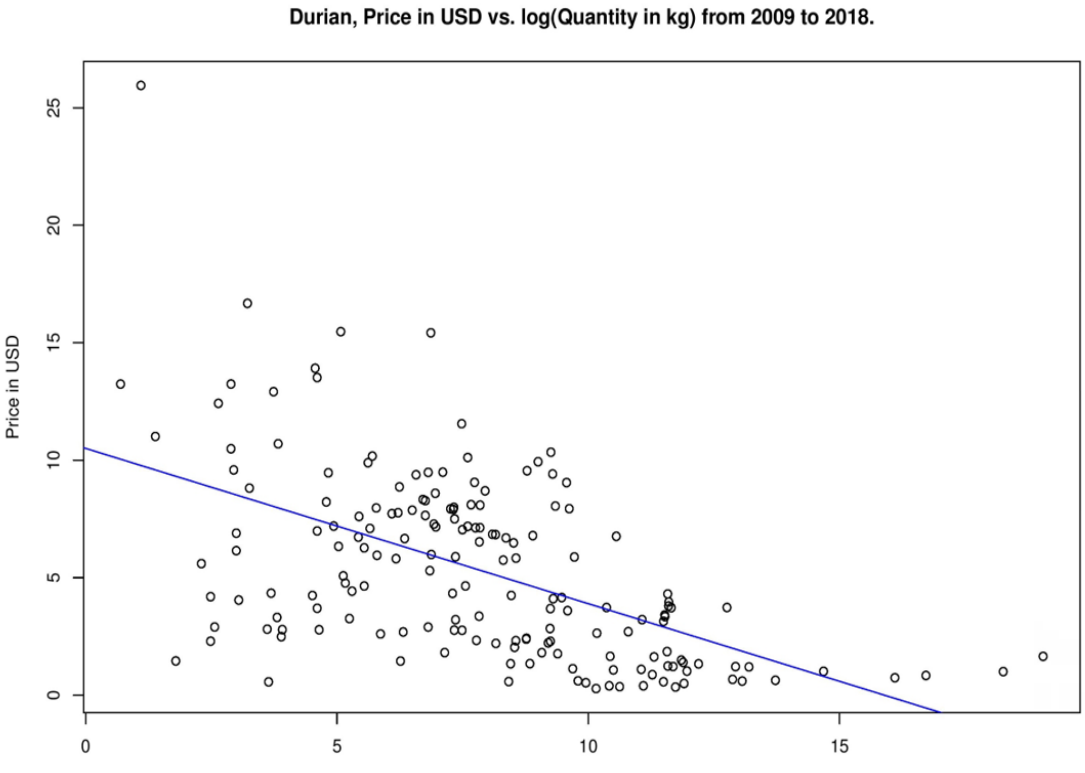
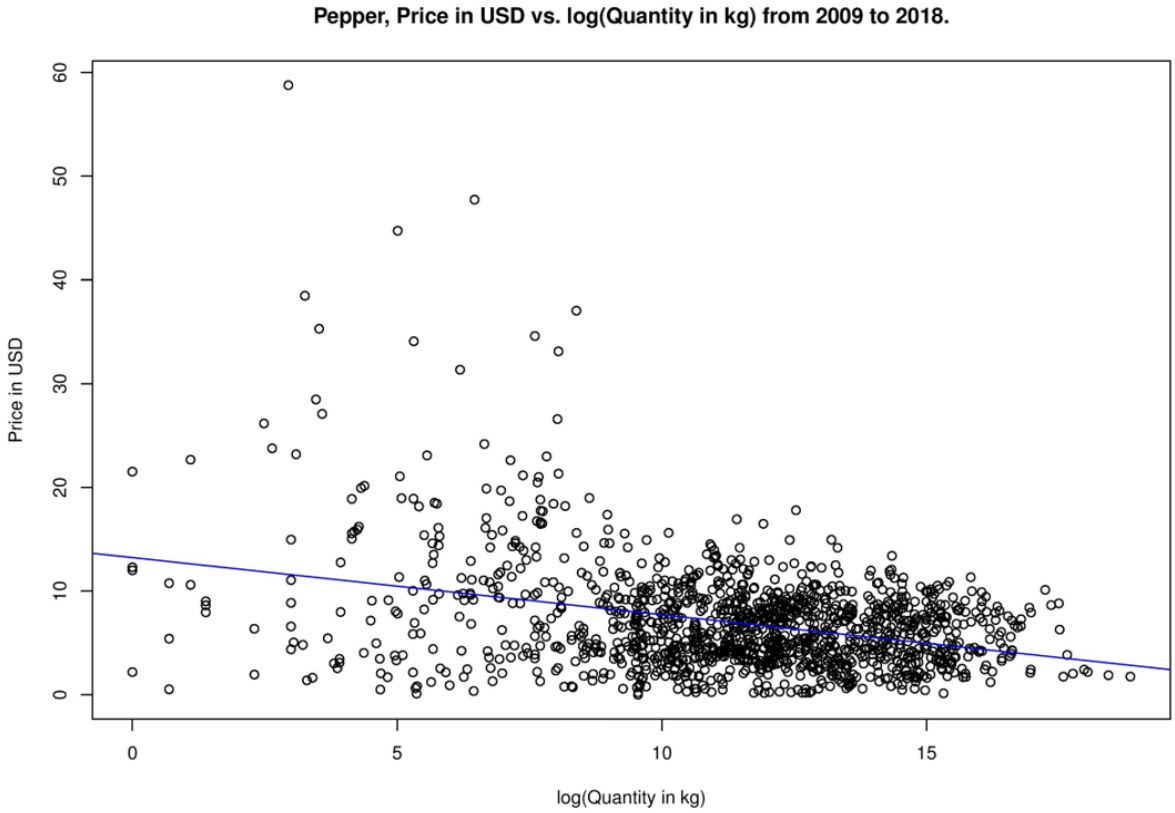


Figure 10: Demand curve for pepper, based on trade data where Vietnam was the originating partner.



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