1. Title and project coordinator
Project title: The Agroforestry Paradox - Climate Clever Coffee (APCCO).
Coordinated by Associate Professor Aske Skovmand Bosselmann, University of Copenhagen.

2. State of the art and rationale
The project is about Ugandan coffee, the people who cultivate it and the environments in which it grows. Though coffee agroforestry systems (AFS) offer many benefits to producers, the major share of global coffee production is from monocrop systems, which place production and livelihoods in jeopardy in the face of climate change. We will integrate new knowledge from multiple perspectives and disciplines concerning agroforestry (AF), incl. crop-tree-climate interactions and human ecological dimensions of AF, leading to understanding of this paradox. We will apply a digital modelling tool to develop hyper-localized models of AF systems and their outputs, develop scenario-based AF decision support, and co-design new business models for producers, traders, and roasters leading to market-driven, inclusive coffee value chains based on climate-smart AF. APCCO will examine the agricultural transformations among Ugandan coffee farmers, and channel our core findings into a scalable, scenario-building methodology coupled with economically feasible business models, applicable to smallholder coffee farming across the tropics. The project will be anchored at farm-level but build knowledge with and for the entire coffee value chain and its stakeholders to benefit from climate-smart agroforestry.

Climate change (CC) is the largest challenge to agriculture across the globe, with regions of Africa being among those most affected (1,2,3). CC stands to exacerbate poverty levels in African countries, particularly due to the sheer number of smallholders who are vulnerable to climate hazards and erratic seasonal patterns (4,5). AF has long been promoted as a poverty alleviation strategy (6,7) and more recently been heralded as a climate smart practice (8). AF, loosely defined as 'agriculture with trees', increases carbon uptake and storage, buffers extreme weather and builds resilience against CC, and simultaneously produces multiple farm products and increases overall productivity, while lowering the need for costly inputs (9,10,11). Despite well-documented benefits of AF (12), increasing CC risks to farmers worldwide, and supportive policy frameworks (13), there has been an overall lower than expected adoption of AF across the globe (8, 14, 15); thus, forming what we term "the agroforestry paradox". This paradox remains widely unexplored. Recent reviews of AF adoption studies conclude that existing research is limited and non-consistent in identifying factors that promote adoption, inadequately addressing the complex dynamics and systemic nature of the context-dependent AF adoption processes (12, 16, 17).

The AF paradox is well exemplified by coffee production. Coffee originates in the understory of forested areas of Africa (18) and thus has an inherent adaptability to shaded systems such as AF. The coffee crop is highly threatened by CC, such as increasing temperatures (19, 20). Yet, open-field, monocrop farming is most commonly practiced today, a result of decades of conventional intensification of coffee farming (21). Given this path dependency, there is less uptake of AF as a known CC adaptation strategy than ever before (21,22). Robusta coffee (*Coffea canephora* Pierre ex Froehner) makes up almost half the global production of coffee and is highly relevant in terms of acreage, farmers and production on the African continent (23,24). However, past research efforts have focused on how Arabica coffee (*Coffea arabica* L.) interacts in AF environments, while Robusta coffee has been largely left behind, partly due to its perceived tolerance for higher temperatures (25). New reports now show that Robusta coffee is equally vulnerable to CC (26, 27), yet specific CC adaptation strategies are largely based on Arabica-research (22, 25, 28).

Global coffee production has tripled since 1970s, but the African output has been stagnant. Uganda is the exemption having doubled the acreage over the last decade, making coffee Uganda's top crop and export commodity, generating earnings of $657 million in 2021 (29). An estimated 1 million households, mainly smallholders, cultivate Robusta in Uganda (29). Productivity is low and access to agricultural training and inputs is limited. Meanwhile food insecurity is common among coffee communities and farmers experience a large living income

gap, i.e., their net income does not afford their household a basic, yet decent living (30,31). In addition, Uganda is considered a high-risk region for CC impacts (32). A more widespread use of shade trees is part of the national coffee strategy (29), but farmers who intercrop shade trees often favour a few exotic species not selected based on AF-coffee compatibility, thus lowering the systems overall resilience (33,34). There is also limited knowledge of how Ugandan coffee AF adoption and implementation depends on local conditions and farmers' species-specific knowledge (33), and how on-farm decisions affect vulnerable groups (*i.e.*, women, youth and elderly) (35). Given these research gaps, we dedicate APCCO to the Robusta crop and specifically to Robusta farming in Uganda.

Improved knowledge of the many interactions in coffee AFS holds the potential to optimize AFS design to meet farmers' priorities, as well as improve process-based AFS models to model growth, yield and ecosystem services within these systems (36, 37). Digital tools to model performance across different agro-ecological contexts of Robusta farms are still in a young development phase. Existing models require many input parameters, which makes their feasibility from a data-availability in a Ugandan context unclear. There is a need to review and calibrate the existing process-based models to determine modelling suitability for the specific context of Ugandan Robusta AFS. The actual application of these models, specifically through Information and Communications Technology (ICT) enabled support services, is equally important (38). Despite the growing literature on digital agriculture, it is still unclear what impact ICT-enabled support services have on the adoption of climate smart agriculture amongst coffee farmers and the potential socio-economic benefits to farmers (39, 40).

The AF paradox seems partly caused by fragmentation of knowledge at several levels, incl. science, practitioners and policy (12, 15). Through the APCCO project, we propose to disentangle the biophysical, socio-economic, and knowledge-based drivers and/or challenges leading to the AF paradox. We propose to create digital 'twins' – digital versions of farms - of Ugandan Robusta AFS and model scenarios of farm-specific AFS incl. multiple crop outputs and carbon build-up. By doing this, we will improve decision-making in the design of AFS for increased crop-tree synergies, ultimately for the benefit of the farmer and a reduced living income gap.

An extended hypothesis of APCCO is that new business models, which are economically viable for smallholders and downstream value chain actors, are required to resolve the AF paradox. Various scaling pathways exists for climate-smart value chains including carbon offsetting, impact investment, voluntary certification (41,42), and carbon insetting, i.e., the generation of carbon credits in AF systems offering innovative opportunities for shared producer–buyer value creation (43, 44). However, engaging smallholders in new AF based business models, such as carbon markets, is challenging and highly context-dependent with no easy-to-use methodology nor dominant business model currently available (41). A better understanding of the various mechanisms influencing the design of such business models is needed. Transformation of value chains require a systemic approach to innovation involving both main primary chain actors, and services and support provided by the enabling environment (45). Innovation platforms and 'living labs' (46) that relies on a participatory approach to co-design, implement and test new solutions can be successful mechanisms to transform value chains (47, 48). APCCO proposes to establish a 'living lab' that brings together partners and stakeholders in the Ugandan and Danish coffee value chain to co-create, test and iteratively improve new integrated climate-smart AF-based coffee business models.

3. Relevance and context

The APCCO project is aligned with Sustainable Development Goals (SDGs) 1, 2, 5, 10, 11, 13 and 15 as well as many other global environmental and economic development initiatives. The London Declaration (49) - the first global joint commitment of public and private actors in a tropical commodity sector - acknowledged the need for reversing global deforestation and forest degradation trends. This is the starting point for the APCCO project, which aims to examine the nature-based solution of Robusta agroforestry as a climate change mitigation and adaptation strategy (work packages - WPs 1 & 2; addressing SDG 13 & 15). Moreover, the need to enable

a living income for producers is stressed multiple times in the Declaration and the resulting Coffee Public Private Task Force under the International Coffee Organization. APCCO matches this aim with its efforts to reduce poverty and improve food security amongst coffee farmers (SDG 1 & 2). By providing the cultural, agronomic, farm economic and market linkages, APCCO will provide holistic solutions for Ugandan coffee farmers, thus building more climate and economically resilient rural communities in Uganda (SDG 11).

CC resilience is a major priority for the Ugandan government and a key aspect in the National Coffee Strategy 2040. Uganda's Nationally Determined Contribution Partnership Plan (NDC-PP) against climate change (50) aims to reduce CC vulnerability and build resilience of climate sensitive and key sectors (50). This includes the coffee sector - the focus of APCCO. APCCO's objectives are also aligned with the Development Directorate of the Uganda Coffee Development Authority (29), which promotes and oversees the Ugandan coffee industry. Work packages (WP) 1-2 address the agenda of the Directorate through the promotion of both "good agricultural practices and agribusiness", facilitated by scenario-building digital tools in WP3 (with real farmers as first-users). UCDA supports agroforestry development but lack reliable interdisciplinary sources of knowledge about climate change impacts and adaptive strategies. Protecting vulnerable groups (including women, youth and elderly) is considered a crosscutting issue for the development of the NDC-PP and UCDA and are incorporated into WPs 2, 4 and 5 (also addressing SGD5 & 10).

By developing pathways for climate-smart agriculture and improving farmers' resilience, APCCO is aligned with Denmark's strategy for development cooperation (51). The APCCO project will strengthen UG's largest export sector with strategic guidance and participation from Danish businesses and is thereby aligned with the existing framework by The Danish Trade Council and DANIDA in UG. APCCO shares mutual goals with the ongoing Uganda Programme for Sustainable and Inclusive Development of the Economy (UPSIDE), which is dedicated to creating sustainable and inclusive economic growth based on agricultural development, with coffee being one of the main value chains. Through close collaboration with UPSIDE's implementing partner Agricultural Business Initiative (aBi) and with IFAD's Africa Rural Climate Adaptation Financing Mechanism (ARCAFIM), as well as Denmark in Uganda, APCCO can reap the rewards from lessons already learned through UPSIDE and help to reach the goals of the initiative through WP4's novel business models. We prioritise the inclusion of vulnerable community members (i.*e.*, women, youth and elderly) into the economic activities of WP4. To formalise these goals, our advisory board includes members from aBi, ARCAFIM and NuCAFE (social coffee enterprise), and APCCO will liaise with the Danish Embassy in Kampala.

APCCO will be implemented in the context of a Ugandan coffee sector comprised of a multitude of actors. First, 1 million smallholder farmers' livelihoods depend on coffee, which often make farmers wary of new AFS technologies or management. This risk adversity may be part of the AF paradox, and as such is part of the research. We will collaborate with Kawacom, partner of Peter Larsen Kaffe (PLK) that works with local lead farmers in the study areas, and who can facilitate trust. Second, international commodity traders present in Uganda and national coffee enterprises are in varying degrees involved in farmer capacity building as part of corporate sustainability efforts. Therefore, we expect a large interest in APCCOs outputs and outcomes. Third, national authorities see coffee as a key sector for economic development, which APCCO supports through scientific results and capacity building among a key public actor (NaCORI).

4. Objectives

The project's objectives are to (i) uncover key interactions between shade trees, coffee plants, ecosystem services and the socio-economic and cultural context within Ugandan coffee AFS and (ii) render a comprehensive understanding of and solution to the AF paradox by linking interdisciplinary research with cross-sector actors and development of new AF-based business models.

We hypothesize that the AF paradox arises at the interface between biophysical evidence, farmers' knowledge and decision-making practice and the institutions that surround them. Only by understanding these factors and triangulating knowledge between disciplines will it be possible to design AFS that are climate smart, inclusive and economically viable. We hypothesize that collaboration with the private sector can provide a lever for increased adoption of AF through valuation of ecosystem services, such as carbon payments, premiums for agroforestry grown coffee and value added from AF tree crops.

Table 1 lists the specific objectives and related research questions. A fifth specific objective is to strengthen the capacities of research and business development in the UG public and private coffee sector. This is achieved through the education of 4 PhD students and improved collaboration between academia and UG coffee research institutions, among others, and through the establishment of a 'living lab' for AF-based Robusta business development with participation of UG coffee actors from both the public and private sectors.

Table 1 Specific objectives and key research questions

Specific objective	Research questions
1. To elucidate critical interactions between UG Robusta AF and coffee productivity, carbon sequestration and responses to abiotic/biotic stresses	• How are Robusta coffee yield and phenology affected by AF compared to full-sun systems (FS)? • What is the carbon sequestration potential in AF and FS Robusta coffee systems? • How do abiotic (e.g., drought) and biotic (pests and diseases) stresses influence Robusta coffee under AF and FS? • Which shade tree species are compatible with Robusta AFS in terms of low occurrence of pests and diseases, nutrient and water competition?
2. To uncover socio-economic and cultural aspects of Robusta AFS adoption and practices among smallholder farmers in UG	• How diverse are Ugandan Robusta (AF) coffee smallholder farms in terms of shade tree species richness? • What are the cultural and socio-economic reasons for (non)adoption of Robusta AF systems, including perceived ecosystem services and disservices of shade trees? • How do shade trees contribute to the household economy?
3. To assess the potential impact of digital tools on the design and adoption of hyper-local AFSs and living income gap in UG	• To what extend can existing biophysical models for ecological and economic modelling be calibrated to accurately model Robusta AFS in Uganda? • How can hyper-local, scenario-based digital support tools increase AFS adoption? • How do Robusta FS/AFS affect farmers' ability to earn a living income? • What are the potentials of ecosystem services-based Robusta AF farming on living income gap reductions (scenario-based modelling)?
4. To develop ecosystem service-based business models that integrate Robusta AFS and are socially desirable, technically feasible and economically viable for the UG coffee sector	• Which specific demand-side and local supply-side conditions need to be considered in the design of integrated AF-based coffee business models? • Which types of local support/services are needed to introduce, scale and sustain a climate-smart coffee business model in UG? • How can innovative market platforms, such as Era of We, and agri-business incubators support and drive implementation of ecosystem service-based (e.g., carbon) coffee business models?

5. Expected outcomes and outputs

Despite Robusta coffee makes up almost half the World's coffee production and provide a livelihood for millions of farmers, the bulk of coffee research as focused on Arabica coffee. In particular, limited interdisciplinary Robusta research has been conducted on the African continent. APCCO addresses this through the main expected scientific results (i) a greatly improved understanding of interactions and links between biophysical, social, institutional and

socio-economic aspects of Robusta AF, (ii) new digital modelling capacities of the performance of Robusta AFS to support AFS adoption, business development and improved understanding of living income gap reductions, as well as (iii) a co-design process aimed at developing ecosystem services-based business models for climate clever Robusta AF. New knowledge will be accessible to relevant stakeholders (cf. section 11), incl. local authorities in UG working to improve the coffee sector and increase rural incomes. APCCO is also expected to prototype 'climate clever' coffee business models, which adds a fourth dimension to 'climate smart' by making commercial enterprises a supporting feature of AFS. Table 2 details the outcomes and outputs of APCCO.

Table 2: Expected outcomes and outputs

Outcomes	Targeted Outputs
• In-depth understanding of applicable CC mitigation practices for UG coffee farmers (WP1/2 synthesis); translated into policy & best practices for increased climate resilience of coffee farms. • Awareness among public and private stakeholders of the socio-economic and cultural importance of tree species diversity in Robusta coffee systems; subsequent introduction AFS guidelines as CSA in Uganda national strategy for the coffee sector. • An understanding of how AFS can be designed and implemented to support a living income among smallholder farmers; subsequently applied to policies among Uganda coffee authorities. • Wide application of digital tools for Robusta AFS implementation in hyper-local settings across UG, leading to flexible, climate-smart coffee AFS, catering for individual farmers' priorities. • New climate-clever coffee business models implemented and capacity established to continue co-development of business models for joint value creation among the UG coffee value chain actors. • Strengthened research capacities among Ugandan academic and applied research institutions. • Collaboration among business, policy, finance and producer stakeholders for expansion of Robusta AFS in UG • Comprehensive understanding of the AF Paradox among key stakeholders in the global coffee sector and pathways for solutions integrated in agricultural policies	• 4 PhD students, defended • 16 research articles • 2 Policy briefs • 5 Technical reports • Research stays of 6 senior UG scientists in Denmark • 2 Farmer outreach events • 6 databases • 6 Social media videos • News features (online/paper) • A Living lab and 4 co-creation processes for climate-clever business models • 3 Prototype AFS-based business models • Project website • 5 annual progress reports

6. Methodology

The project comprises of five interlinked WPs (Fig. 1 above). WP1 and 2 will be conducted simultaneously with partially shared field missions across two of the main Robusta growing areas in UG, covering Kyankwanzi/ Mubende and Rakai/ Lwengo/ Masaka, representing dry/ wet conditions, respectively, and different vegetation zones. Kawacom, Peter Larsen Kaffe's partner in UG, will facilitate access to large farmer networks. Empirical work in WP3 will commence once WP1/2 data become available, while WP4 is also informed by WP1-3 but initiates independently. WP5 is cross-cutting and will be the driving force for interdisciplinary collaboration and knowledge-exchange between partners and external stakeholders.

WP1 (*coffee and the agroforestry system*) will investigate biological and agricultural aspects of the UG Robusta AFS with focus on CC. Climate stressors and tree-coffee-environment interactions (under natural and artificial shade as well as drought conditions) will be studied across a range of farms in UG presenting different conditions in terms of precipitation and elevation. By using real UG coffee farms, WP1 activities will provide hyperlocal data for the subsequent WPs activities. Microclimate modifications in coffee AF systems are highly shade species dependent (52). WP1 will investigate how shade species in UG coffee AFS affect coffee plants. Robusta coffee-producing farms will be identified in collaboration with WP2, and farms will be selected to cover a shade gradient from open-field (full sun) to mature/dense AF. Plots will be established under selected shade tree species and in the open, applying a randomized

block design with high statistical power (53) and assessments carried out on both field and plot levels. In a second research design, WP1 will set up infrastructure to study the effects of shade on Robusta performance. This will be done on-farm through the establishment of shade nets above rain interceptors in a replicate block design.

In both approaches, Robusta coffee plants and the accompanying on-farm shade trees will be assessed for eco-physiological and yield traits as well as inter-canopy and/or farm level microclimate modifications. Phenology and yield assessments will be made at critical time points in the crop cycle (i.e., during vegetative bud formation, flowering, pinhead expansion and harvest) and in multiple years to capture effects of climatic variations. Biotic stressors (incl. black coffee twig borer and coffee wilt disease) will be monitored for incidence and prevalence during natural infection periods. Eco-physiological aspects of both the coffee plant and shade trees will include gas-exchange (for estimations of carbon assimilation and stomatal conductance), leaf hydraulic conductance, water potential, as well as tree root mapping through soil cores. Total carbon sequestered in the Robusta systems will be assessed based on soil carbon using CHN analyser (54), bulk density estimates (55) and crop and tree root and stem biomass using existing allometric equations (56). Coffee samples will be harvested and processed for quality assessment, informing WP4 of technical coffee qualities in varying AF systems.

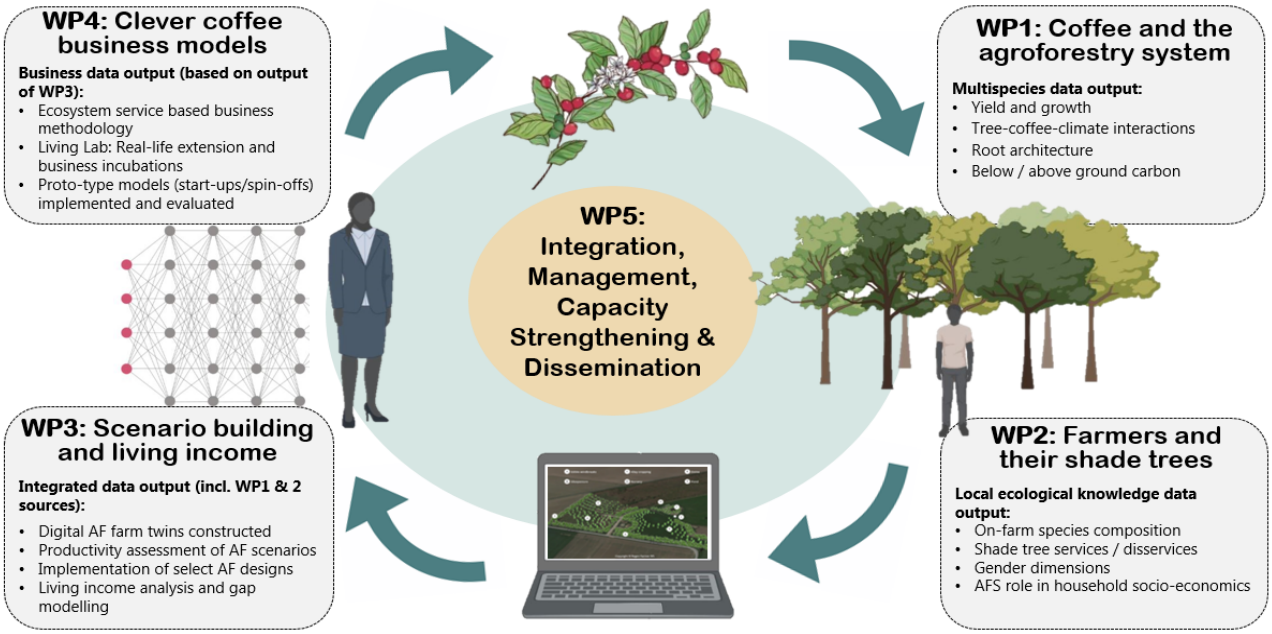

Figure 1 The organisation of work packages in APCCO

WP2 (*farmers and their shade trees*) will uncover farmers' perceptions and adoption of Robusta AFS, by assessing on-farm tree species richness using inventory methods, and socio-economic aspects and farmers' LEK of trees and their services/disservices, using surveys, interviews (57) and Q-methodology (58) (cf. WP1).

We will assess on-farm tree diversity through tree inventories in randomly selected plots (n=100 farming households), aiming at characterizing coffee-AFS typologies and representation of full-sun systems found in the study area. Male and female household heads (n=200 in the 100 inventoried households) will be interviewed separately about reasons for (non)adoption of coffee-AFS, and reasons for shade tree species selection (LEK), including perceived ecosystem services and disservices (ES/ED), cultural and economic reasons. We will then conduct a household survey with the inventoried households and additional 200 randomly selected households, to assess FS and AFS management practices (inputs and outputs) and assess the contribution of shade trees and coffee (in FS and AFS) to the household economy, including cash and subsistence income. We will apply the Q methodology to the subset of farmers who have adopted AFS to rank the shade tree species according to famers' perceived ES/DS. The ranking will depict the most suitable species according to ES/ED and preferences of the farmers. WP2

data will be triangulated with findings in WP1 and fed the 'digital twin' model and living income assessment in WP3, as well as support the Living Lab in WP4.

WP3 (*Scenario building and living income*) will assess the most suitable process-based models concerning feasibility, data availability and accuracy requirements for modelling hyper-local Robusta AFSs in Uganda. The models found most suitable will be calibrated with data on system performance from WP1/2 and integrated with Regen Farmers hands-on agroforestry scenario modelling software. 'Digital twins' will be created for 15 farms in collaboration with local agricultural extensionists and farmers. AF transition scenarios will be modelled based on the digital twins and the calibrated process-based models and the most favourable scenarios will be selected for implementation. RegenFarmer's framework model for ecology-socio-economic performance of AFSs makes it possible to further explore and identify scenarios that incorporate multiple output and income streams (link to WP4), such as diverse product outputs, and premium payments or carbon credits (Fig. 2). The technology acceptance model (59) will be used to evaluate the tools in designing potential AF interventions in Uganda, through user testing and interviews with agricultural extensionists and farmers. The participating farmers' level of AF adoption will be analysed.

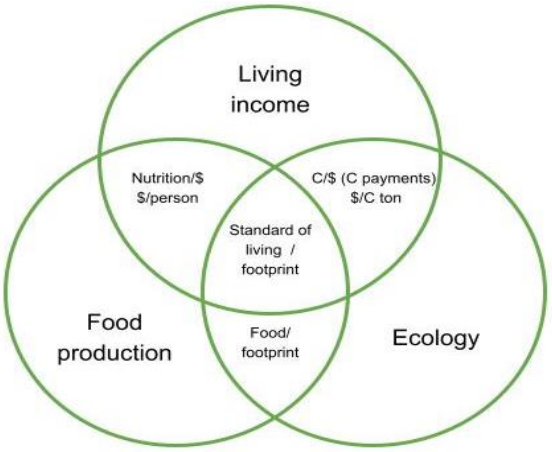

Figure 2. Framework for productivity by RegenFarmer

A novel living income (LI) methodology, by NewForesight, will be integrated in the WP, creating new insights on AFS' role in living income gap closure. The LI methodology follows the Ankers' methodology (60) in principles, guidelines and standards, but rely on databases supplemented with specific primary data to generate a valid, context-specific, yet comparable LI benchmarks. In each study area, primary data are collected from 15 representative farmers regarding costs of living and 3 food markets to understand local food prices and food availability for a model diet. The benchmark is validated by external stakeholders. A LI gap assessment, i.e., difference between benchmark and actual incomes (WP2 data), is conducted for farmers with varying degrees of AFS and combined with scenario outputs of the Regen Farmer software to assess relations between income gaps and AFS characteristics. Potential drivers influencing the variations in income gaps will be analysed using regression analyses to evaluate the potential contribution of AFS systems in closing income gap.

WP4 *(clever coffee business models*) will review existing literature on coffee business models involving ecosystem services, carbon credits, and other innovative approaches from both demand and supply sides. We will use interviews and a survey to understand roasters and traders' perceptions of customer value and logistic requirements and benefits of various types of innovative business models. Using interviews, focus groups and document reviews, we establish a thorough understanding of the dynamics of the local UG business ecosystem and institutional context. Drawing on these analyses and information from WP2, we will establish a 'living lab' (47, 48) develop a value chain development strategy, and implement a process, where value chain stakeholders jointly apply design thinking tools (61,62) and co-creation (63, 64, 65) to co-develop with farmers and business partners locally optimized novel business models. This may include carbon services, quality based on environmental convention, and tree crop products. In this process, we apply the AF scenario modelling based on Regen Farmer's tool (WP3) to quantify commercial opportunities and evaluate the business model designs. The co-development process aims at launching at least one prototype business model on the online retail platform Era of We (66), developed by Peter Larsen Kaffe and catering for short value chains for quality or specialty coffee. Linking to WP1-3, the new business-models, jointly designed with DK and UG private sector partners, will be assessed, and learnings used to promote real-life AF extension and business incubations by NARO and CURAD.

WP5 is dedicated to the **integration, management, capacity strengthening and dissemination** of APCCO, as outlined in Section 8 below. Regular online and biennial physical meetings/ discussions, including annual advisory board meetings, will facilitate sharing of insights, co-design of next critical steps and shape project outcomes. WP5 also coordinates ethical and GDPR related approvals concerning survey and interview data. Informed consent will be obtained from all survey participants and interviewees and data will be anonymized. APCCO partners will respect the Vancouver rules for co-authored publications.

7. Overview of the research plan

Table 3 below outlines the major activities and milestones of APCCO, while Table 4 presents the APCCO research team, incl. person-months and contributions to WPs.

Table 3. Gantt chart of project activities and milestones.

Work packages	Main Activities / Year / Quarters	2023 1/4	2023 2/4	2023 3/4	2023 4/4	2024 1/4	2024 2/4	2024 3/4	2024 4/4	2025 1/4	2025 2/4	2025 3/4	2025 4/4	2026 1/4	2026 2/4	2026 3/4	2026 4/4	2027 1/4	2027 2/4	2027 3/4	2027 4/4	Description of main milestones
WP1. Coffee and the agroforestry system	Identification of experimental field trial sites																					1. Formalisation of experimental field trial farms 2. Shade quality Survey (inventory, w. WP2), and quantity (light interception). 3. Stressor trial sites established. 4. Field trial mesaurements complete. 5. Stressor trial measurements complete.
	Shade tree species inventory (w. WP2)																					
	Ecophys/agron. data collection in fields																					
	Establishment & implementation of stress trials																					
	Ongoing analyses of farm data for use in WP2 &3																					
	Milestones		1				2				3		4 5				4 5					
WP2. Farmers and their shade trees	Identification and selection of coffee farms																					1. Random sampling of Robusta farms. 2. Plots established, species ID performed (w.WP1). 3. Farmer AFS adoption survey done. 4. Soc-economic HH survey done. 5. Tree suitability ranking.
	Shade tree species inventory																					
	Farmer interviews, HH survey, Tree ranking																					
	Data-exchange to / from WP1,3&4																					
	Milestones		1				2	3			4		5									
WP3. Scenario building and living income	Setup digital twins, scenario modelling																					1. Digital twins created; living income (LI) benchmark. 2. Mechanistic models and LI model integrated. 3. Data from WP1+WP2 (incl. LI) integrated. 4. Scenarios modelled. LI gap analysis done. 5. Evaluation of AFS.
	Model and data integration																					
	Living income benchmark and gap analysis																					
	AFS adoption assessment for participating farms																					
	Milestones						1				2		3		4					5		
WP4. Clever coffee business models	Living lab strategy and planning workshops																					1. Methodology & strategy for Living Lab ready. 2. Value chain analysis conducted. 3. Business model/value chain config. approved. 4. Climate clever business model operational. 5. Evaluation report.
	Value chain - supply and demand-side analysis																					
	Co-creation workshops - business model design																					
	Implementation & evaluation of new value chain																					
	Milestones							1			2				3	4					5	
WP5. Management, Capacity Strengthening & Dissemination	Inception and Project workshops																					1. Advisory board established. 2. Project websites established. 3. Annual accounts and reports. 4. Policy briefs. 5. Final reporting
	Closing and stakeholder seminar																					
	Advisory board meetings																					
	Online progress reporting and dissemination																					
	Milestones	1	2				3				3				3		4	4	3		5	
PhD students (& MSc student milestones)	UG Course work, 2 research stays in Denmark																					1. PhDs recruited. 2. PhD courses passed. 3. PhD proposals accepted. 4. MAK & UCPH MSc thesis defended (7) 5. Presentations at IFRO/IGN seminars. 6. Theses submitted
	Field work																					
	Data analysis, thesis writing, article writing																					
	Milestones		1				2,3		4				4				5		6			

Four PhD students will be enrolled at Makerere University (MAK), with main supervisors at MAK and co-supervision by the research team in Denmark, including partners from RegenFarmer (RF) and NewForesight (NFS). Two PhD students will be engaged in climate-crop-tree interactions and ecophysiology in WP1, and two PhD students will collaborate on the ethnobotanical and socio-economic aspects of AFS in WP2, while also spending time and efforts in WP3 (approx. 40 %) and WP4 (approx. 60 %), respectively. Four distinct calls for PhD applicants will ensure the right student profiles are attracted.

In WP1 to 4, research design development, data collection and analysis, and writing will be carried out in collaborative DK-UG research teams. While prolonged fieldwork periods will mainly be conducted by the PhD students, DK researchers will join their UG colleagues conducting field work each year in the project.

8. Organisation and management

APCCO is a Danish-Ugandan collaboration comprising of 22 dedicated experts from 8 partner institutions. Danish partners in APPCO comprise the closely-knit departments of Food & Resource Economics and Geosciences & Natural Resource Management at UCPH. Participating researchers have vast experience with research in tropical societies and tree crops, and collectively cover business innovation, socio-economic, institutional and agronomic/biology aspects of the project with high-level expertise. In Denmark, they are supplemented by

RegenFarmer (RF) that offer expertise in crop modelling and development of user-friendly IT tools for farmers, and Utrecht-based NewForesight (NFS) that is spearheading living income assessments across the globe. The Ugandan side is represented by a strong team of researchers from College of Agricultural & Environmental Sciences at Makerere University (MAK), the National Coffee Research Institute (NaCori) and the Mukono Zonal Agricultural Research & Development Institute (MuZardi). All participating researchers have previous professional experience with coffee. The project is strengthened by participation of the private sector in Uganda through the Consortium for enhancing University Responsiveness to Agribusiness Development (CURAD), and in Denmark through Peter Larsen Kaffe (PLK), who is engaged in circularity, quality and new coffee business development. The project is coordinated by Dr. Aske S Bosselmann (IFRO-UCPH) with project management experience from FFU, Horizon2020 and Nordic Climate Facility funded projects, implemented across 3 coffee-producing continents. To ensure continuous DK-UG coordination of activities, each WP is co-lead by researchers in both countries (cf. Table 4).

Table 4. Participating scientists and their role in different work packages.

Participating scientist (person-months)	**Expertise**	**Institution**	**Role in work packages**				
			WP1	WP2	WP3	WP4	WP5
Dr. Aske S Bosselmann (14)	Resource economist	UCPH		C	C		L
Dr. Anders Raebild (8,3)	Agroforester	UCPH	L	C			C
Dr. Nico Portefée Hjortsø (9)	Business development	UCPH				L	C
Dr. Nerea Turreira Garcia (11)	Ethnobotanist	UCPH		L			
Ms. Athina Koutouleas (15,5)	Eco-physiologist	UCPH	C				
Prof. Jacob Godfrey Agea (7)	Applied Agriculturalist	MAK		C	L		
Dr. Jenipher Bisikwa (9,5)	Agronomist	MAK	C	C			L
Dr. Jeninah K.-Tumutegyereize (9)	Entomologist	MAK	C				
Dr. John Bosco Lamoris Okullo (9)	Agroforester	MAK	C	C			
Dr. Susan Tumwebaze (9,5)	Carbon models/stats.	MAK	L	C			C
Dr. Catherine Mulinde (11,5)	Climate scientist	MAK	C	C	C		
Mr. Apollo Segawa (12)	Agri-business develop.	CURAD			C	L	C
Dr. Pascal Musoli (3)	Coffee breeder	NaCori					C
Dr. Godfrey Kagezi (7)	Plant health scientist	NaCori	c				
Dr. Godfrey Sseremba (7)	Crop scientist	NaCori	C	C			
Dr. Pauline Aluka (7)	Agronomist	NaCori	C				
Dr. Apolo K. Katwijukye (7)	Socio-economist	NaCori			C	C	
Dr. Sarah Mutonyi (11)	Agroforester	MuZard		L	C	C	
Mr. Kristoffer Rønn-Andersen (11)	AFS modelling	RF			L	C	C
Ms. Christina Singh (2)	Innovation manager	PLK	C			C	C
Mr. Daniel Pedersen (2)	Agri. Economist	NFS			C	C	C
Mr. Emmanuel Ahovi (2)	Agri. Economist	NFS		C	C		

Work package contribution: Leader (L), Contributor (C).

Annual project meetings as well as continuous WP-level meetings will ensure continued activity planning and implementation among project partners. An Advisory Board will be set up, consisting of Prof. S. Kyamanywa (MAK), G. Okidi, Head of Portfolio at aBi, J. Nkandu, executive director of the social coffee enterprise NuCAFE, and a representative from ARCAFIM. The selection of Ugandan stakeholders, representing different actors in the coffee sector, ensures physical meetings are possible and that APCCO activities are aligned with national interests and priorities. The advisory board reviews and comments progress reports and plans in connection with the annual project meeting and prior to project reporting.

9. Capacity strengthening

Research capacity strengthening will take place through research-based education of 4 Ugandan PhD students and joint DK-UG research activities across all work packages (WP) spanning natural science, digital agriculture, development policy, ethnobotany, business development, socioeconomics, as well as publication processes. The PhD students will enjoy

two research stays of 3 and 5 months duration at UCPH, incl. tailored courses, writing workshops and retreats, and daily participation in the local research environment. A shorter research stay at UCPH is planned for senior researchers from MAK and NaCORI. The UG partners will present their work at faculty level dissemination events, and DK partners will share resources and access to relevant academic courses (e.g. Preferred Reporting Items for Systematic Reviews and Meta-Analyses and Advanced Scientific Writing) as well as applicable library databases agreements. New scientific equipment will also be purchased by the DK partners and provided to MAK/NaCORI to allow for state-of-the-art in-field measurements (during and after the project).

10. Partnerships

The project is highly relevant to both private and public actors in the coffee value chain. The partnership with PLK and other private actors in the living lab aims for product line expansion of specialty, shaded Robusta coffee, enabling market differentiation of PLK, local UG businesses and UG farmers. The UG coffee research community will benefit from closer collaboration between research teams in academia, the national research institutes and at private companies, while CURAD, as well as APCCO's relation to aBi, ARCAFIM and NuCAFE, will help to bridge research, agribusiness development and possibly financing mechanisms. APCCO will liaise with the HorizonEurope RIA project BOLERO (2022 – 2026), which investigates grafting for low-input coffee systems *i.a.,* in Uganda and have NaCORI as a partner and A. S. Bosselmann (UCPH) as WP leader. APCCO will also be closely aligned with the DeSIRA project ROBUSTA, which recently started in Uganda, led by French CIRAD and coordinated by former project partners of IFRO and IGN. Like APCCO, the ROBUSTA project focuses on climate adaptation, though mainly from a breeding perspective. Finally, APCCO researchers are already connected to a collaboration of DK and UG NGOs working on agroforestry promotion.

11. Publication and dissemination strategy

Results from the project will be disseminated continuously across various communications platforms, coordinated by leaders of each WPs, supported by private and local partners existing access to information outlets, and directed at different arenas, incl. academic, policy, professional and popular (cf. outputs in Table 2). When possible, scientific publications will be published with open access (OA), an option we can pursue through UCPH OA agreement with several publishing houses. The involvement of NaCORI and MuZardi, both under the National Agricultural Research Organization, ensures APCCOs results are made available to the national coffee research community, in English as well as in Luganda, which is one of the main local languages among coffee farmers. Results and outcomes from the Living Lab hosted by CURAD will be disseminated within the agribusiness community through the CURAD-aBi collaboration and their involvement in the African Agribusiness Incubator Network. During the project and at its closing, we will use formal dissemination events for key project stakeholders, incl. university partners, local rural partners, the Danish Embassy in UG, the UG Ministry of Agriculture, Animal Industry and Fisheries, UCDA and representatives of NDC-PP. By succinctly communicating project outcomes to relevant authorities, APCCO stands to influence new policies and programs and top-level actions concerning coffee production in UG.

MAK will establish a designated project website, where WP leaders will communicate project progress, news, events and results. Results of general public interest and awareness purposes will also be shared through online newspapers, Ag magazines, and social media. PLK will support dissemination of short videos through their international network. One video, introducing the AF Paradox from a Ugandan coffee field, has been recorded. Upon completion of research activities, WP teams will disseminate results for outreach and educational purposes, such as with Kawacom technicians in the field for ICT supported AF outreach, public presentations of PhD student thesis, and contributions to Master level courses and thesis work. All non-commercial digital documents and outputs (policy frameworks, business models, datasets etc.) will be made open source, incl. in Luganda when relevant. This will ensure that tropical research centers, coffee agencies and national authorities have access to our findings and outputs, which can support further development and expansion of coffee AF systems.

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