AI-DRIVEN CLIMATE-SMART BEEKEEPING FOR WOMEN IN ETHIOPIA AND UZBEKISTAN

Final Project Report | 2021

ICARDA

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Contents

Acknowledgements

The authors would like to thank:

The 39 project beekeepers for sharing their beekeeping experiences, feedback, and testing the app.

icipe, who provided technical backstopping services in-kind and through the YESH project (funded by the MasterCard Foundation) to women beekeepers including materials for bee forage, refresher training on apiary management, experience sharing between model beekeepers, and marketplace linkage support.

The Association of Beekeepers of Uzbekistan, who supported the organization of workshops with project beekeepers and supported local project promotion and publicity.

The ICARDA Uzbekistan office, for their coordination and advice on engagement of project stakeholders in Uzbekistan, their hospitality to international staff during the final workshops, and strategic thinking to move the project forward.

HiveTracks, for their adaptation and innovation to embark on a new type of project to localize their Beekeeper's Companion app for Uzbekistan and Ethiopia, and dedicated staff who put in extra time for troubleshooting and support to local teams.

The AID-CSB Advisory Group, a group of international experts in beekeeping, innovations scaling, and rural development, who met with project management every one to two months to provide constructive feedback and advice on future project activities.

The German Federal Foreign Office, who not only provided funding but furthermore ensured a strong commitment to human rights, biodiversity, and climate change mitigation throughout the project.

This report was co-authored by independent consultant Dr. Sarah-Beth Hopton, Laura Becker, and Max Rünzel, with review by Laurens Tetzlaff, and Jakob von Grünberg, and design by Sarah Denton, who also served as the UX/UI designer on the project.

Acronyms

ABU	Association of Beekeepers of Uzbekistan
AI	Artificial Intelligence
AID-CSB	AI-Driven Climate-Smart Beekeeping for Women
BIPOC	black, indigenous, and other people of color
EMA	economically motivated adulteration
GDP	gross domestic product
GMO	genetically modified organism
ICT4D	information communication technology for development
ICARDA	International Centre for Agricultural Research in the Dry Areas
icipe	International Center of Insect Physiology and Ecology
ID	identity
FAO	Food and Agriculture Organization
MEL	monitoring, evaluation, and learning
MOYESH	Young Entrepreneurs in Silk and Honey
nuc	nucleus colony
PPP	public-private-partnership
SMS	short message service
TET	transparency enhancing technology
UI	user interface
U.S.	United States
UX	user experience

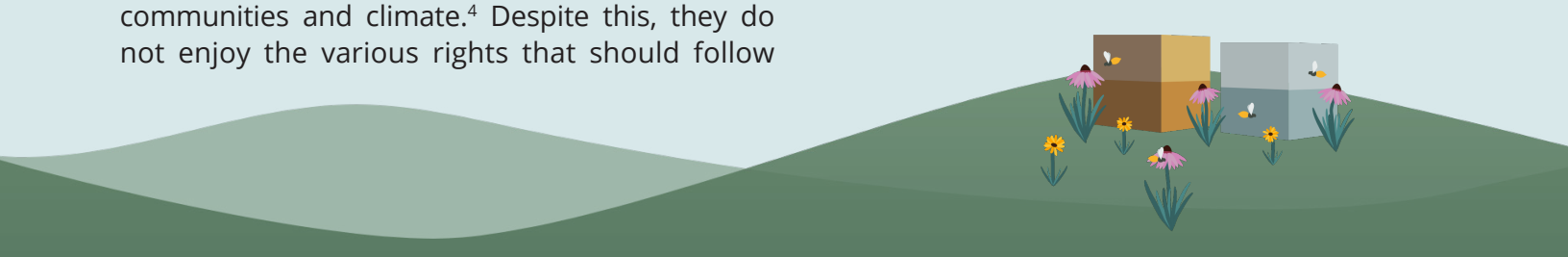
Executive Summary

Humanity depends on services that nature provides. We are especially dependent on pollination services, through which human food systems either flourish or fail. As global warming and anthropogenic climate change threatens, disrupts or devastates natural ecosystems; human rights to clean food and water, economic stability, and personal health and safety are also in jeopardy.

While many climate-mitigation policies and technologies treat biodiversity loss, global warming, and human rights as independent of each other, they are not. Disruption in one system disrupts the other systems to which they are connected. For example, the overapplication of agricultural chemicals that support a monocrop system of food production needed to feed seven billion people, results in habitat loss for pollinators. Habitat loss is a key contributor to recent declines in honeybee populations, which impacts the human right to health and food.[1] Thus, any mitigating technical solutions, policy changes, or practices should be designed holistically, with consideration given to global warming, biodiversity loss, and human rights impacts collectively,[2] and those solutions should be co-designed with the very people who are disproportionately affected by climate change: women, children, and Black, Indigenous people of color.[3]

Worldwide, women have proven that they are not only key contributors to agricultural labor, making up 50% of the workforce, but that they can drive innovative solutions that positively affect their communities and climate.[4] Despite this, they do not enjoy the various rights that should follow their agriculture work, including financial autonomy, equal pay to men, land ownership, and environmental health. Beekeeping is unique in that it does not require land ownership but can still provide women with a source of income and a kind of labor opportunity that can be performed at home while taking care of other domestic responsibilities. Home-based or small-scale beekeeping can also give women voice in local community climate-mitigation policy.

The *AI-Driven Climate-Smart Beekeeping (AID-CSB) for Women* project worked with beekeepers in Uzbekistan and Ethiopia to co-design and localize the "Beekeeper's Companion", a climate-smart information communication technology for development (ICT4D) app designed to support beekeepers' hive management practices and improve honey production. AID-CSB's ambition is to work towards applying advanced machine learning models on standardized biodiversity data by mitigating bias and maintaining spatial and temporal accuracy. To do this, the project leverages the participation of women beekeepers and national experts and incorporates their traditional and local knowledge into the algorithms that will push information to the beekeepers. Recognizing the need for an agricultural solution that does not require more time from women, the app was designed so that uploading data points requires a minimal time investment. For example, recording information on a hive inspection can be done with a simple swipe gesture in under five seconds.



1 Andrea Willige, "75% of Crops Depend on Pollinators: they must be protected," World Economic Forum, December 9, 2019, https://www.weforum.org/agenda/2019/12/protect-pollinators-food-security-biodiversity-agriculture/

2 H. O. Pörtner, R.J. Scholes, J. Agard, A. E. Archer, A. Arneth, X. Bai, D. Barnes, M. Burrows, L. Chan, W. L. Cheung, S. Diamond, C. Donatti, C. Duarte, N. Eisenhauer, W. Foden, M. A. Gasalla, C. Handa, T. Hickler, O. Hoegh-Guldberg, K. Ichii, U. Jacob, G. Insarov, W. Kiessling, P. Leadley, R. Leemans, L. Levin, M. Lim, S. Maharaj, S. Managi, P. A. Marquet, P. McElwee, G. Midgley, T. Oberdorff, D. Obura, E. Osman, R. Pandit, U. Pascual, A. P. F. Pires., A. Popp, V. ReyesGarcía, M. Sankaran, J. Settele, Y.J. Shin, D.W. Sintayehu, P. Smith, N. Steiner, B. Strassburg, R. Sukumar, C. Trisos, A.L. Val, J. Wu, E. Aldrian, C. Parmesan, R. Pichs-Madruga, D.C. Roberts, A.D. Rogers, S. Díaz, M. Fischer, S. Hashimoto, S. Lavorel, N. Wu, H.T. Ngo, "IPBES-IPCC co-sponsored workshop report on biodiversity and climate change," IPBES and IPCC (2021): 1–28.

3 David R. Boyd, "Report of the special rapporteur on the issue of human rights obligations relating to the enjoyment of a safe, clean, healthy and sustainable environment," United Nations General Assembly, A/76/150. (2021): 1–26.

4 "Women as Agents of Change," United Nations Climate Action, https://www.un.org/en/climatechange/climate-solutions/womens-agents-change

Use of the app will narrow the gender digital divide by increasing women's digital literacy but it will also give users valuable information they can use to manage and grow their operations. Notably, many global digital projects fail because development firms too frequently design *at* users not *for* them. The participatory design method used in this project reverses this process and involves stakeholders, designers, researchers, and end users in the design process, ensuring the final product meets the needs of its audience, not the will of the developer.[5]

The latest conclusions from the Commission on the Status of Women (CSW) emphasize that digital technologies have an impact on women's employment opportunities and reduce gender inequities in the face of climate change. Thereby, gender-responsive tech-enabled beekeeping thus unlocks a low-barrier economic activity that also improves local biodiversity, crop yields, and the health of bee populations. These micro-entrepreneurship opportunities directly improve the users' livelihoods while also building community, proving commercial viability, improving local biodiversity, enhancing opportunity independent of land ownership, and securing a place for women apiarists in future development of honey traceability features, which would economically advantage producers producing unadulterated honey products. By supporting healthy hive management practices in small-scale operations, the app also supports resiliency in the face of the COVID-19 pandemic, as beekeepers can access resources and knowledge wherever they are, even when in-person extension services are not possible. Access to such information can help women and their communities become climate-resilient by offering ways to adapt practices to new climatic realities. Finally, the app promotes the health of honey bees while also serving as a proxy information source for the status and health of other pollinators in the area, an essential prerequisite for sustainable agri-food systems in the face of more frequent adverse climatic events.

Key milestones of the project in 2021 included addressing the digital divide through smartphone provision and training; gathering and integrating beekeepers' input through user interviews and prototype testing; and generating localized versions of the app for Uzbekistan and Ethiopia. Encouraged through one-on-one dialogue, women's input was at the center of the project's development process, informing how the interface, content, and gender-sensitive translations should be designed to best support their livelihoods as beekeepers. This innovative, participatory, and gender-responsive design process has proven to be essential to achieving the AID-CSB 2021 goal.

The following report frames AID-CSB activities within the environmental, human rights, and digital contexts in Uzbekistan and Ethiopia; details the preliminary findings of a series of user-tests and iterative participatory application designs of the app; and provides recommendations for bringing the app to scale in Uzbekistan, Ethiopia, and beyond. Lessons learned include the limits of localization, and the careful communication and numerous iterations required to mitigate issues of language, scalability, bias, access and cultural norms around women and technology.

AID-CSB is funded by the German Federal Foreign Office, and implemented by the International Center for Agricultural Research in the Dry Areas (ICARDA)'s Monitoring, Evaluation, and Learning (MEL) team; HiveTracks; and the International Centre for Insect Physiology and Ecology (*icipe*).

5 J. Steinke, Ortiz-Crespo, B, Etten, J. Müller, A, "Participatory Design of Digital innovation in Agricultural Research-for-Development: Insights from Practice, Unpublished Manuscript, Alliance of Bioversity International and CIAT, Digital Inclusion, Montpellier, France; Acharya, K. R. (2017); Usability for social justice: Exploring the implementation of localization usability in Global North technology in the context of a Global South's country, *Journal of Technical Writing and Communication*, 49(1), (2019): 6–32.; Bannon, L. J., & Ehn, P., "Design matters in participatory design," In J. Simonsen & T. Robertson (Eds.), *Routledge Handbook of Participatory Design*, New York, NY: Routledge, (2013): 37–63; Spinuzzi, C., The methodology of participatory design. Technical Communication, 52(2), (2005):163–174; Zachry, M., & Spyridakis, J. H., Human-centered design and the field of technical communication, *Journal of Technical Writing and Communication*, 46(4), (2016): 392–401.

1 | Overview and Key Challenges

1.1 | Women as Agents of Change through Apiculture

Current evidence suggests that a sixth major extinction of biological diversity is underway. The Earth is losing between one and ten percent of its biodiversity per decade, mostly due to land-use/change-induced habitat loss, pollution, over-harvesting and disease related to human population growth and overconsumption.[1] Since species are linked to ecosystems, as one goes extinct, others with which they interact are likely to also go extinct, thus affecting the biodiversity of entire ecosystems and limiting the rights of humans to clean air, water, and access to safe food.[2] Arguably, the most important activities bees (and honeybees in particular) provide are pollination ecosystem services that sustain biodiversity and human foodways. Honeybees and other pollinators enable up to $570 billion in food production worldwide. In fact, one-third of the world's food supply—everything from aubergines to alfalfa—and nearly 80 percent of the world's flowering plants, rely on pollinators, such as honeybees. Thus, their importance to global biodiversity, human food production and climate resiliency cannot be overstated.[3]

Women make up almost half of the agricultural workforce in the world, with growing roles in dryland areas like Uzbekistan and Ethiopia, as they take on additional responsibility and autonomy when men migrate for work.[4] Nonetheless, women are often unpaid and are frequently categorized as "home" producers or assistants, and not accorded the dignity of being considered farmers, apiarists or income-producers in their own right. As with agriculture generally, beekeeping has historically been viewed as a men's activity, but women have always played a significant role in the daily labor required to maintain hive health or to trade and sell honey and hive products.[5] Due to their growing role in apiculture, working with women on innovative agriculture projects can have a ripple effect on communities, agri-food systems, and climate.

The historic marginalization of women has had significant impacts on women's access to land, credit, agricultural extension services, and technology. Such institutionalized discrimination means that women are often less involved in food system planning, policy and decision-making, technology development, or the conceptualization of climate-mitigation strategies,[6] despite overwhelming evidence that when women and Black, Indigenous people of color (BIPOC) are included in these conversations, outcomes are more innovative, and technological solutions are more effective.[7] [8]

1 Edward O. Wilson, *The Diversity of Life*, W. W. Norton & Company, Inc. New-York, (1999).
2 S. G. Potts, V. L. Imperatriz-Fonseca, H. T. Ngo, J. C. Biesmeijer, T. D. Breeze, L. V. Dicks, L. A. Garibaldi, R. Hill, J. Settele, A. J. Vanbergen, M. A. Aizen, S. A. Cunningham, C. Eardley, B. M. Freitas, N. Gallai, P. G. Kevan, A. Kovács-Hostyánszki, P. K. Kwapong, J. Li, X. Li, D. J. Martins, G. Nates-Parra, J. S. Pettis, R. Rader, and B. F. Viana, "The Assessment Report on Pollinators, Pollination and Food Production: Summary for policymakers." Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on Pollinators, Pollination and Food Production, (2016): 1–40. https://ipbes.net/sites/default/files/spm_deliverable_3a_pollination_20170222.pdf
3 Andrea Willige, "75% of Crops Depend on Pollinators: they must be protected," World Economic Forum. (2019). https://www.weforum.org/agenda/2019/12/protect-pollinators-food-security-biodiversity-agriculture/
4 Nomunume Baada, Jemima Najjar. "A Review of the Effects of Migration on the Feminization of Agrarian Dryland Economies." Journal of Agriculture, Gender, and Food Security, 5(2), (2020): 1–12. https://repo.mel.cgiar.org/handle/20.500.11766/12175
5 Tammy Horn, Beeconomy: What Women Beekeepers can Teach us about Local Trade and the Global Market, (Lexington, Kentucky: The University Press of Kentucky, 2011), 1–376.
6 "The State of Food and Agriculture: Women in agriculture – closing the gender gap for development." Food and Agriculture Organization of the United Nations, (2011): 1–160, https://www.fao.org/3/i2050e/i2050e.pdf.
7 "Achieving gender equality and the empowerment of all women and girls in the context of climate change, environmental and disaster risk reduction policies and programmes," CSW Agreed Conclusions, (2022), https://digitallibrary.un.org/record/3956348?ln=en
8 Natasha Primo, "Gender Issues in the Information Society," UNESCO Publication for the World Summit on the Information Society, (2003), https://unesdoc.unesco.org/ark:/48223/pf0000132967.

The AID-CSB project aims to support the social and financial emancipation of women beekeepers through the development of a localized apiary management app designed to promote sustainable agricultural and apiculture practices.

1.1.1 | Why Beekeeping?

Given honey bees' essential role as plant pollinators for biodiversity and food production, it's important to identify threats affecting honey bees and to develop suitable solutions to mitigate biodiversity loss and reverse pollinator decline. Beyond the importance of bees to the world's biological stability, beekeeping has important economic advantages and a longstanding cultural significance over other forms of agriculture that make it especially suitable for a co-designed technical solution that considers human rights, climate change and biodiversity loss as a singular, interconnected problem.

Africa is the birthplace of bees and apiculture, offering humans honey and beeswax that have defined important rituals for centuries: birth, marriage, reciprocal payments, and gifts. The indiginous knowledge accumulated over centuries of beekeeping deserves preservation in its own right, and its incorporation into modern technologies can extend its value, improving hive productivity and also providing information critical to understanding climate impacts and improving community-level climate resilience.

The demand for honey and honey-based products worldwide is growing, and consumers are showing greater interest in high-quality, organic and unadulterated honey.[9] Increased demand translates into the potential for increased profit. Building an apiary requires little upfront investment, as hive frames and boxes can be handmade and honey can be extracted without mechanization (though production at scale without mechanization becomes difficult). Beekeeping also requires fewer inputs (water or agro-chemicals, for example) and less land than other forms of husbandry (like cattle), which means it has fewer climate impacts of its own. Finally, beekeeping is not as physically demanding as some other forms of agricultural labor (though a certain physicality is required).

A beekeeper in Ethiopia at her apiary (Credit: icipe).

These factors combine to create a low-barrier economic entry point into local and regional markets with the potential for healthy returns with manageable start-up expenses and the kind of labor that women can do at home. All told, beekeeping as a micro-entrepreneurship opportunity can result in women's economic sovereignty, improve digital literacy, enculturate women's use of technology, while improving climate resiliency.

1.1.2 | Why Uzbekistan and Ethiopia?

In both countries, climate change-related issues and the lack of available infrastructure to facilitate training and product processing pose significant challenges for beekeepers. Input-intensive agricultural practices of nearby farms also threaten honey bee health and the biodiversity required to promote pollination services vital to local agri-food systems. There is real demand among beekeepers for easily accessible information on beekeeping practices, and among extension and research communities for data on honey bees and beekeepers.

9 UN Comtrade United Nations Commodity Trade Statistic Database, (2020), https://comtrade.un.org/data.

Uzbekistan has a rich tradition of beekeeping and uses honey as a source of both food and medicine. While current annual levels of honey production are relatively low—about 13,000 tons—as compared to other countries like India, which produces 64,900 tons on average (2017–2018).[10] Because of the demand for honey and income it provides, there is little margin for disruption to a beekeeper's system of production. Adverse weather events like higher-than-normal summer temperatures, drought, pollution from nearby manufacturing plants, or significant habitat loss or degradation can imperil a beekeeper's livelihood in Uzbekistan.

As the leading producer of honey in Africa, beekeeping in Ethiopia is widespread. By some estimates, one in ten households keep honey bees.[11] Though present production levels in Ethiopia are almost triple that in Uzbekistan at 50,000 tons, the production potential is much higher—approximately 500,000 tons—due to the country's unique, diverse, and abundant flora and fauna. Mainly produced as a cash crop, around 70% of market honey is used to make the local fermented beverage called Tej, leaving the remaining 30% to be sold as table honey. While trusted beekeeping extension services and projects exist, they cannot feasibly provide in-person assistance to the estimated 11 million beekeepers spread across Ethiopia's changing terrain, which includes hard-to-access rural and conflict-affected areas. Supporting beekeepers therefore requires a solution that they can independently access and use. The pollination services that honeybees provide are also critical to strengthen food systems and reduce food insecurity, a major concern due to recent and ongoing conflict in the North and rain shortages in the Southeast.[12]

Beekeepers in Uzbekistan inspect their hives (Credit: ICARDA).

10 Anjali Marar, "A Sweet Success Story: In 12 years, India's honey production grows by 200%, exports by 207%," India Express, (2019). https://indianexpress.com/article/cities/pune/a-sweet-success-story-in-12-years-indias-honey-production-grows-by-200-exports-by-207-5736611/

11 "Ethiopia's huge honey production potential in search of modern techniques," EURACTIV.com with AFP, (2017), http://www.euractiv.com/section/agriculture-food/news/ethiopias-huge-honey-production-potential-in-search-of-modern-techniques/

12 "Expanding Drought and Conflict are Expected to Drive Severe Food Insecurity in 2022," Famine and Early Warning Systems Network, (2021), https://fews.net/east-africa/ethiopia.

Top photo: Participating beekeepers in Ethiopia receive beekeeping equipment kits (Credit: icipe). Middle photo: Ethiopian beekeepers participate in smartphone training (Credit: icipe). Bottom: Modern and traditional hives in Ethiopia (Credit: Holeta Bee Research Centre).

1.2 | Environment and Human Rights, Gender & Climate Change

1.2.1 | Human Rights, Climate Change & Biodiversity

Access to safe work, shelter, food, and Access to safe work, shelter, food, and environmental health are basic human rights. Yet, these rights are not enjoyed universally, as vulnerable populations, children, BIPOC, and women are disproportionately affected by climate change, which exacerbates existing inequalities.[13] During extreme weather events, for example, women are more likely to die than men,[14] owing to differences in socioeconomic status, financial and decision-making power to access resources and life-saving information. The economic stress induced by extreme weather events can result in spikes of domestic violence against women, or trigger famine and forced migration. On a day-to-day basis in many low-income countries, women are responsible for labor that depends on the climate, such as harvesting coffee in Ethiopia, which becomes more difficult in the face of rising temperatures which enable the spread of destructive pests an decrease the quality of coffee.[15]

Though beekeeping provides a promising low-barrier economic entrypoint for women, many women beekeepers find themselves navigating both typical challenges like pests, pollution, and agricultural pesticides, as well as atypical challenges like violent conflict and theft, as they attempt to manage apiaries. Climate change poses an additional threat to pollinators and honey bees, as decreased precipitation reduces water and nectar sources, and rising temperatures overheat hives, which can kill the brood (eggs). Beekeeping is not only more difficult due to

13 David R. Boyd, "Report of the Special Rapporteur on the Issue of Human Rights Obligations Relating to the Enjoyment of a Safe, Clean, Healthy and Sustainable Environment," United Nations General Assembly, (2021): 1–26.

14 At a Glance: Women, Health, and the Environment," *Our Planet,* United Nations Environment Program, Vol 15 (2): 16–18, https://wedocs.unep.org/bitstream/handle/20.500.11822/8333/-Our%20Planet%20Vol_%2015%20No_%202_%20Women,%20Health%20and%20the%20Environment-2004421.pdf?sequence=5&amp%3BisAllowed=y%2C%20French%7C%7Chttps%3A//wedocs.unep.org/bitstream/handle/20.500.11822/8333/-Our%20Planet%20Vol_%2015%20No_%202_%20W

15 Abaynesh Asegid, "Impact of Climate Change on Production and Diversity of Coffee (Coffea Arabica L) in Ethiopia," *International Journal of Research Studies in Science, Engineering and Technology*, 7(8), (2020): 31–38, http://www.ijrsset.org/pdfs/v7-i8/5.pdf.

the adverse effects of climate change, but it also helps to mitigate the adverse effects, through the generation of income, educating women on technology use, and improving biodiversity.

The relationship between biodiversity and human rights is not always obvious, but consider the right to a clean, healthy, and sustainable environment. Clean water is supported by diverse plants and animals that help remove pollutants and improve water flow by reducing runoff; the reduction of infectious zoonotic diseases is associated with higher biodiversity, and the maintenance of mental health is supported through exposure to nature, which requires biodiversity. Loss of biodiversity exacerbates existing vulnerability and marginalization of indigenous populations who are dependent on natural resources, as they often lack the capital and political power to replace lost resources or compete with wealthy global corporations exploiting their native lands.[16] Particularly among women, depletion of natural resources increases the probability of forced migration and loss of income.[17] Perhaps the most obvious consequences of biodiversity loss and human rights are visible in our food systems. Since diverse plants and crops enrich the nutrients available in soil and mitigate farmer risk in case one crop fails, biodiversity and healthy agricultural practices are a critical link in protecting and strengthening food systems.

Supporting all of these human rights through biodiversity are pollinators. Pollinators help the plants that become medicine reproduce and flourish. Healthier plants root deeper and live longer, which, depending on whether those plants are in soil or water, affects oxygen levels and food supplies to and for microorganisms essential to biotic life. Strong pollination services can shorten the time between flowering and fruiting, thus reducing risks associated with pests, disease, and weather while concurrently decreasing the need for application of agro-chemicals, which strengthens ecological systems. Ultimately, pollinator services can improve a beekeeper's productivity, preserve and restore the biodiversity of the habitats they rely on to provide these services; in turn also protecting the indigenous knowledge required to maintain healthy hives and the culturally significant role bees have always played in human health and happiness.

Though women could and should play a significant role in solving the climate-related problems that disproportionately affect them, they are often left out of such conversations and negotiations. Yet when women are included in the planning and implementation of climate-smart solutions, the solutions are more sustainable and efficient.[18] The most recent conclusions from the CSW emphasize that an enabling environment is needed to support women and girls to participate in climate change solutions; in part by strengthening women's access to education and technology. AID-CSB takes the co-design approach with women beekeepers by gathering their input and testing climate-mitigating features within the Beekeeper's Companion app, such as notifications on blooming plants and weather, and integrating their feedback into newer iterations of the app.

1.2.2 | Threats to Biodiversity, Pollination, & Cultural Practice

Herbicides, nitrogen-based fertilizers, heavy metal supplements, and animal effluent contribute to staggering[19] levels of air, land, water, and marine pollution, all of which deleteriously affect pollinator habitat or feeding routines. Air pollution, for example, is particularly hard on bees, as it shortens the distance flower scents can travel, confusing bees and attracting them to what

16 "Human rights obligations relating to the enjoyment of a safe, clean, healthy and sustainable environment," United Nations General Assembly, (2019), A/76/150. https://undocs.org/en/A/76/150

17 "Achieving gender equality and the empowerment of all women and girls in the context of climate change, environmental and disaster risk reduction policies and programmes," CSW Agreed Conclusions, (2022), A/62. https://digitallibrary.un.org/record/3956348?ln=en

18 "Analytical Study on Gender-Responsive Climate Action for the Full and Effective Enjoyment of the Rights of Women," United Nations General Assembly Human Rights Council, (2019), https://undocs.org/A/HRC/41/26.

19 David R. Boyd, "Report of the Special Rapporteur on the Issue of Human Rights Obligations Relating to the Enjoyment of a Safe, Clean, Healthy and Sustainable Environment," United Nations General Assembly, (2021): 1–26.

appears to be food but is not. This problem is especially common where hives are located near manufacturing plants producing sugary products like sodas, as is the case for several women bee-keepers in Uzbekistan.

Threats to biodiversity of habitat also threaten diverse cultural practices and indigineous ways.[20] The protection and promotion of culture is a human rights imperative and a human-centered approach to technology development can safe-guard heritage, strengthen creative economies, while encouraging cultural pluralism. Before technology made it possible to collect digital data or manage hives remotely, grandmothers and grandfathers taught their grandchildren how to see and make use of information on bloom cycles, habitat, weather, pestilence and breeding—all of which is necessary to maintain healthy hives. They taught the next generation how to speak the language of bees, a language composed not of words, but of touch, scent, and dance.[21]

Though indigienous knowledge of bees is immense in places with long apicultural histories like Uzbekistan and Ethiopia, this knowledge is under its own kind of threat, with fewer young people becoming beekeepers. Project partners theorize this is because youth want fast money and perceive the time investment to be too long in Uzbekistan, or the danger due the aggres-siveness of subspecies of *Apis mellifera* bees in Ethiopia, too high.[22]

"The protection and promotion of culture is a human rights imperative and a human-centered approach to technology development can safeguard heritage, strengthen creative economies, while encouraging cultural pluralism."

1.3 | Gender Digital Divide

Close to half the world remains offline and the majority of those without access to internet con-nection in developing countries are women,[23] but lack of accessibility only explains part of the digital gender divide. For the past 30 years, experts working at the intersections of gender and ICT4D theorized that digital literacy and skills, cost, and availability of delivery mechanisms (like cell phones) were the principal reasons for the gender digital divide.[24] Certainly these factors continue to contribute to the divide, but new research suggests that norms have an equal and sometimes greater impact on women's access to and use of technology.[25] Many women in low-in-come countries have cell phones or access to communication technology because they are allowed to and millions of women do not have access to tech because of family, community, legal[26] or religious regulations[27] that order women to protect themselves or preserve their dignity

20 David R. Boyd, "Report of the Special Rapporteur on the Issue of Human Rights Obligations Relating to the Enjoyment of a Safe, Clean, Healthy and Sustainable Environment," United Nations General Assembly, (2021): 1–26.
21 Patrick H. Wells, Adrian M. Wenner, "Do Honey Bees Have a Language?" *Nature* Vol. 241 (1973): 171–175, https://doi.org/10.1038/241171a0
22 "Honeybee Species and Subspecies," Wikipedia, Edited April 15, (2021), https://wiki.sams-project.eu/index.php/Honey_bee_species_and_subspecies
23 Carlos Iglesias, "The Gender Gap in Internet Access: Using a women-centred method," Web Foundation, March 10, (2020), https://webfoundation.org/2020/03/the-gender-gap-in-internet-access-using-a-women-centred-method/
24 Carmen Steele, "What is the Gender Divide?," Digital Divide Council, February 22, (2019), http://www.digitaldividecouncil.com/what-is-the-digital-divide/
25 Sterling, Revi, Lauren Grubbs and Thomas Koutsky, "Breaking Through the Gender Digital Divide: Technology, social norms, and the WomenConnect challenge," *ERN: Information Asymmetry Models* (Topic), (2020); Richard Joiner, Caroline Stewart, and Chelsey Beaney, *The Wiley Handbook of Psychology, Technology, and Society*, eds. Larry D. Rosen, Nancy Cheever, L. Mark Carrier, (Hoboken, NJ: John Wiley & Sons, Ltd, 2015), 74–89.
26 Rina Chandran, "Indian Villages Ban Single Women from Owning 'Distracting' Mobile Phones," Reuters, February 16, (2016), https://www.reu-ters.com/article/us-india-women-phone/indian-villages-ban-single-women-from-owning-distracting-%20mobile-phones-idUSKCN0VZ1AA.
27 Madeline Grant, "Egyptian Sslamic Authority Issues Fatwas Against Selfies and Chatting Online," *Newsweek*, September 1, (2014), https://www.newsweek.com/egyptian-islamic-authority-issues-fatwas-against-selfies-and-chatting-online-%20267832; L. L. Dodson, Leslie, R. Sterling, and J. K. Bennett, "Minding the Gaps: Cultural, technical and gender-based barriers to mobile use in oral-language Berber communities in Morocco," *Proceedings of the Sixth International Conference on Information and Communication Technologies and Developmen*t, 1, (2013): 79–88.

"As the world becomes increasingly technology-dependent, the consequences grow for those who are left behind. Technology responsively designed through participatory processes can reduce this divide."

by abstaining from use. Even in more relaxed cultural settings, technology is often considered a tool specific to and appropriate for men and community members sometimes regard women who use technology with suspicion or scorn.[28] Isolation from familial and community groups can seriously threaten womens' health, safety, and economic security. Furthermore, the COVID-19 pandemic exacerbates challenges of affordability, accessibility, and technology use and has been particularly difficult to manage for women in rural communities already living at the economic margins. Degendering the digital divide and technology solutions requires development partners to improve digital literacy, skills, decrease cost of access, customize delivery mechanisms, consider and–where possible–incorporate or disrupt the normative values and attitudes associated with gender and technology.[29]

While technology is not a panacea, ICT4D solutions can catalyze and empower women and BIPOC communities, especially in agriculture. Coupling women's existing knowledge about agri- and apiculture with responsively-designed technology could result in a force-multiplier effect in mitigating climate-related problems like pollinator decline. Technology acts as a gateway for women to access information that can radically improve their livelihoods and those of their family and community. By some estimates, doubling the number of women online in developing countries has the potential to increase global gross domestic product (GDP) by an estimated U.S. $13–18 billion.[30]

For this multiplier effect to emerge however, the ICT4D community must prioritize participatory design, localization, and the degendering of technology in interventions. As the world becomes increasingly technology-dependent, the consequences grow for those who are left behind. Technology responsively designed through participatory processes can reduce this divide.

28 Eric Bellman and Adita Malhotra, "Why the Vast Majority of Women in India Will Never Own a Smartphone," Wall Street Journal, October 13, 2016. https://www.wsj.com/articles/why-the-vast-majority-of-women-in-india-will-never-own-a-%20smartphone-1476351001

29 Mary K. Feeney and Federica Fusi, "A Critical Analysis of the Study of Gender and Technology in Government", Information Polity, 26(2), (2021):115–129; Huatong Sun, "Exploring Cultural Usability," *Proceedings of IEEE International Professional Communication Conference*, (2002): 319–330; Jutta Weber and Corinna Bath, "Social' Robots & 'Emotional' Software Agents: Gendering Processes and De-Gendering Strategies for 'Technologies in the Making," *Gender Designs IT*, (2007): 53–63.

30 Dalberg, Globescan, "Women and the Web: Bridging the internet gap and creating new global opportunities in low and middle-income countries,"Intel, (2012): 1–104, https://www.intel.la/content/dam/www/public/us/en/documents/pdf/women-and-the-web.pdf.

2 | Project Team & Participants

To participate in narrowing the gender digital divide, support women's livelihoods, and reverse pollinator declines, ICARDA's MEL team, HiveTracks and *icipe*, partnered to make available and localize a beekeeping application for beekeepers in Uzbekistan and Ethiopia called the Beekeeper's Companion, which helps beekeepers more effectively manage their hives and collects data important to scientific research on pollinator populations. Recognizing that rural women and women smallholder farmers should be given the opportunity to participate fully in project activities that affect their livelihoods and resilience[31], the majority of project beekeepers are women, who participated in all stages of the project (from design to use).

AID-CSB leveraged the public-private-partnership (PPP) model because PPPs transfer certain risks to the private sector and provide incentives for assets to be maintained while lowering infrastructure costs to public organizations by reducing development and project life-cycle expenditures. Additionally, PPPs can introduce private sector technology and innovation at speeds and scales that most public services cannot.[32]

2.1 | Project Partners

2.1.1 | ICARDA

ICARDA is an international nonprofit organization that undertakes applied research-for-development aiming at reducing poverty and enhancing food, water, and nutritional security and environmental health in the face of global challenges. Their MEL team supports the decision-making and impact of research through four areas of expertise: M&E, knowledge management, data management, and software development.

2.1.2 | HiveTracks

HiveTracks is a small US-based private company that has developed software for beekeepers since 2010 and has supported 38,000 beekeepers across 150 countries since then. HiveTracks works to create a positive impact on bee health, beekeeper livelihoods and biodiversity by connecting people, nature and data.

2.1.3 | icipe

icipe's mission is to use insect science for sustainable development, to ensure food security and improve the overall health of communities in Africa by addressing the interlinked problems of poverty, poor health, low agricultural productivity and environmental degradation.

2.2 | Participating Beekeepers

2.2.1 | Beekeepers in Uzbekistan

Of the 23 beekeepers[33] interviewed, the majority, 18, were part of a family business; three were hobbyists and two were solo operations or entrepreneurs. Some of the operations are multi-generational, while other beekeepers married into the business, which their husband's or husband's family-owned. The average number of hives in an apiary was 56 but some commercial beekeepers managed up to 200. Even some of the hobbyists maintained 20 or more hives, but all participants—with the exception of one beekeeper who only kept five hives of her own as part of a larger family business—had large apiaries.

31 "Achieving gender equality and the empowerment of all women and girls in the context of climate change, environmental and disaster risk reduction policies and programmes," CSW Agreed Conclusions, (2022), A/68. https://digitallibrary.un.org/record/3956348?ln=en

32 "Government Objectives, Benefits and Risks of Public Private Partnerships," World Bank, updated December 4, 2020, https://ppp.worldbank.org/public-private-partnership/overview/ppp-objectives.

33 Note: one beekeeper had a last-minute conflict and was unable to attend her interview.

Though honey was the primary source of income for all beekeepers, some also sold colonies, queens, propolis, royal jelly, and assorted beekeeping tools or equipment like hive boxes and frames. The majority of honey sales transacted at supermarkets, bazaars and between villagers or extended families. Five beekeepers also sold honey on Telegram, (a cloud-based freeware that allows for instant messaging across platforms), and three beekeepers sold to sanitariums (health spas). Colonies (of bees) are sold through ads on Telegram, and some participants had large enough operations they were sought out specifically through that channel.

2.2.1 | Beekeepers in Ethiopia

Of the 15 beekeepers, ten are family operations, three are independent beekeepers, and two are members of cooperatives. The average number of hives is 25, ranging from five to 100 hives.

Generally speaking, Ethiopian beekeeping purposes range from pursuing it to sustain a livelihood by selling honey and hive products, to passively entertaining hives solely as a tool for domestic consumption and agricultural risk minimization by means of improved crop pollination. Accordingly, the effort invested differs in terms of regular vs rare apiary visits. The most common income-generating products are honey and beeswax of which the majority are sold at local markets and minor portions are shipped to different cities across the country. Honey refinement depends on hive type; honey from modern hives is harvested via manual honey extractors, while product from transitional and traditional hives can be sold in less refined forms, as comb-honey, or as a crushed and mixed honey. Daughter colony selling can serve as a secondary source of generating income.

2.3 | About the Technology: The Beekeeper's Companion App

Launched in 2010, the first HiveTracks' app was designed to help beekeepers manage hive data that had traditionally been recorded by hand and was often difficult to assess longitudinally and therefore of limited value both to the beekeeper or the scientific community. Originally designed as a web app for North American beekeepers, the words, symbols, hive types, queen types, pest species and even the logics of use were US-centric, despite this version of the app being used in 150 countries. Through the AID-CSB project, the new version of the app—the Beekeeper's Companion— underwent iteration to localize the app for Uzbekistan and Ethiopia. This process required extensive desk and user research to understand and later customize the user interface and application functions across three different languages (Uzbek, Russian, and Amharic), different climates, for vastly different user profiles and to accommodate different beekeeping practices.

The app is mobile only, offline capable, and creates a true digital companion for beekeepers, aimed at generating season and location-based information, reminders, and decision-making aids that beekeepers need to protect hives from weather and climate risks, pests, disease, and nutritional deficiencies and malpractices. Though the beekeepers own their data and that data is protected—thus protecting privacy of women users— in the future, scientists and researchers will be able to access non-identifiable aggregated data, to understand the variables associated with honey bee health and the local conditions exacerbating pollinator declines, while giving voice to women whose voices in agricultural policy and technological production have been historically silenced. The app is a stepping stone towards AID-CSB's overarching goal: Building data-driven, user-centric and discrimination-aware solutions to monitor, evaluate and manage biodiversity impacts on and of the honey supply chain while creating value for the individual beekeeper.

3 | Co-design of Digital Technologies for Monitoring, Mitigating & Adapting to Climate Change

3.1 | Theory

3.1.1 | Important principles of co-design

Recent publications in the fields of technical communication and usability studies have highlighted the need to critically examine usability methods, practices, and meanings in response to numerous social issues including cultural sensitivity;[1] community and inclusion;[2] environmental design;[3] accessibility;[4] social justice;[5] and participatory culture.[6] Many global digital projects fail because development firms too frequently design at users, not for them. The participatory design[7] method reverses this process, and involves stakeholders, designers, researchers, and end users in the actual design of the user interface and app functionality, ensuring the end product meets the needs of its audience, not the will of the developer.

Localization is defined as "creating or adapting an information product for use in a specific target country or specific target market."[8] At its roots, localization of products (e.g., interface, design, communication messages) increases the likelihood that the target users will experience the product in intended and favorable ways. Yet localization is not enough. True participatory design processes require co-designing with users. Co-design is a movement, a methodology, and a mindset. It challenges the imbalance of power when one group of people makes decisions that affect the livelihoods of other groups of people, usually marginalized people who, traditionally, have rarely had input in the decision-making process but are impacted by the decisions made. Co-design of technology, specifically, challenges this through inclusivity and by recognizing the importance of different forms of knowledge, especially indiginous knowledge, and by sharing the power to create. There are four primary principles of co-design: sharing power; prioritizing relationships; using participatory means of feedback collection; and building capacity.

1 H. Sun, "The Triumph of Users: Achieving cultural usability goals with user localization," Technical Communication Quarterly. 15(4), (2006): 457–481.
2 A. Shivers-McNair, "Localizing Communities, Goals, Communication, and Inclusion: A collaborative approach,"Technical Communication, 64(2), (2017): 97–112
3 D. Sackey, "One-Size-Fits-None: A heuristic for proactive value sensitive environmental design,"Technical Communication Quarterly, 29(1), (2020): 33–48.
4 A. Hitt, "Foregrounding Accessibility through (Inclusive) Universal Design in Professional Communication Curricula," Business and Professional Communication Quarterly, 81(1), (2018).
5 B. Shirley, "Working toward social justice by engaging other disciplines in engaging communities: A technical communication scholar's role," Proceedings for 2019 CPTSC Annual Conference, (2019).
6 K. R. Acharya, "Usability for social justice: Exploring the implementation of localization usability in Global North technology in the context of a Global South's country," Journal of Technical Writing and Communication. (2017): 6–32.; K. R. Acharya, "Usability for User Empowerment: Promoting social justice and human rights through localized UX design," Proceedings of the 36th ACM International Conference on the Design of Communication, (2018).
7 Revi Sterlingand Tom Koutsky, "Understanding the Gender Digital Divide: Social Norms and the USAID WomenConnect Challenge," 46th Research Conference on Communications, Information, and Internet Policy, (2018), https://ssrn.com/abstract=3142049.
8 N. L. Hoft, *International Technical Communication: How to Export Information about High Technology*, (New York, NY: Wiley & Sons, 1995).

3.1.2 | Bias

Despite its potential, there are bias concerns with technology design -- even that which is co-designed based on participatory methods. "Smart" apps, including the Beekeeper's Companion app, revolve around data-driven rules and algorithms that pave the way towards more advanced statistical methods, such as machine learning. Research has shown that rules and algorithms contained within smart apps tend to inherit the bias of developers. This is particularly the case when inputs, operations and training mechanisms are neither visible nor auditable by third parties, and considered a "black box." Biased outcomes implicit in the decision-making process may not be the intent, but can certainly be the byproduct of development. For example, when operating in an openly or subconsciously patriarchal society, machine-learning algorithms could also learn and proliferate this bias.

To develop fair artificial intelligence (AI) and discrimination aware data-driven apps, several steps need to be accounted for. In line with the six phases for non-discrimination by design, and by developing and localizing the Beekeeping Companion, the app mitigates the unintended consequences of its data-driven and automated functionalities to the greatest extent possible. Starting at the problem and use case definition of the model, the phases of development follow these steps:

Following the best practices of design thinking and usability, each of these steps is either localized, customized, or incorporates user feedback and then prototypes are rapidly produced and users test again in an iterative cycle. For example, after defining the purpose and necessity of potential statistical models alongside their impact on all stakeholders and determining required success criteria, data is selected based on quality, size (which affects storage) and origin (to minimize biased inputs). Similarly, data preparation follows a transparent and thoughtful process that includes defining inclusion and exclusion and determining specific integration and aggregation criteria. Pre-modelling, model selection, technical and user tests are focused thereafter. Ultimately, user testing is only applied to implementation and evaluation, but the participatory model of application development requires ethical consideration of users at every step of the process and model alterations rely on continuous, iterative user evaluation and feedback.

In order to ultimately arrive at a sound and responsible implementation of AI, the first two steps have been the focal points in this stage of the project, with a particular focus on data collection, which has proven to be a key enabler for future implementation of statistical models.

In line with this process, the app development has followed the principles that aim to limit the bias inherent in the design of technology associated with data collection by using a gender-responsive co-design process detailed in the next section.

3.1.3 | User Privacy

The right to privacy is enshrined in article 12 of the Universal Declaration of Human Rights,[9] article 17 in the legally binding International Covenant on Civil and Political Rights,[10] and in article 16 of the Convention of the Rights of

9 *Universal Declaration of Human Rights*, UN General Assembly, 10 December 1948, 217 A (III), https://www.refworld.org/docid/3ae6b3712c.html.
10 *International Covenant on Civil and Political Rights*. United Nations, Treaty Series, UN General Assembly, vol. 999, (1966): 171, https://www.refworld.org/docid/3ae6b3aa0.html

the Child.[11] There are also many privacy laws designed to protect personal data from state actors and corporations and the right to privacy intersects with many other human rights such as freedom of expression, the right to seek, receive and impart information and freedom of association and assembly. Privacy also helps ensure accountability should data be stolen and incorporating strict data privacy protections helps build trust between the user and developer. The app protects user data and ensures privacy through compliance with best practices as outlined by the Bee XML Data Standardization group, including rounding location data to the nearest three km (about 1.8 miles) and aggregating beekeepers' data at regional levels, which further anonymizes data, thus protecting identity and privacy and improving safety for women.

3.2 | Practice/Implementation in the AID-CSB Project

3.2.1 | Methodology

The AID-CSB project leveraged a 3-step process to localize the Beekeeper's Companion app, that independently supported the mitigation of bias and protection of user privacy:

1) Desk research was conducted to gather both a general understanding of the honey sector and beekeeping practices, as well as collect specific data points to be used later on in the app development, such as flowering calendars.

2) Preliminary user interviews were conducted to understand the day-to-day beekeeping experience, practices, and challenges of project beekeepers in order to design the app prototype.

3) Prototype testing enabled women beekeepers to interact directly witenabled women beekeepers to interact directly with the app prototype to identify problems and areas of improvement early, so designers could make the necessary changes prior to development and build products that meet user needs and expectations. During the testing, which was conducted via Zoom, the user experience/user interface (UX/UI) designer requested the beekeeper to complete certain tasks or test certain functions of the app, and observed both their real-time navigation choices, while collecting verbal feedback. The participants were not exposed to any version of the app or to the wireframe prototypes prior to testing to minimize bias. For simplicity, to avoid creating stress for the participants, and to include those users who did not yet have access to a smartphone, the prototype(s) were displayed on a laptop and screen-shared during testing. This process promoted feedback on the user interface and sharing of technical beekeeping information in users' native language(s), which is one way to be gender-inclusive during technology design processes.

The AID-CSB project participants included 24 beekeepers in Uzbekistan (20 women and four men) across two regions: Tashkent (agricultural/rural) and Bukhara (desert). In Ethiopia, 15 beekeepers (12 women and three men) were selected from *icipe's* Young Entrepreneurs in Silk and Honey (YESH) project across three sites in the Amhara region. After communicating the purpose of the interview/prototype testing and receiving beekeeper consent, meetings were conducted and recorded over Zoom with the HiveTracks UX/UI designer and a local translator, and later transcribed. Additionally, information was recorded via physical notetaking, which was then recorded in electronic documents for reference and qualitative analysis by HiveTracks and ICARDA.

Preliminary user interviews and prototype testing were scheduled with the following considerations in mind:

11 *Convention on the Rights of the Child*, United Nations, Treaty Series, UN General Assembly, vol. 1577, (1989): 3, https://www.refworld.org/docid/3ae6b38f0.html

- **Morning and early-afternoon interview times** were most convenient for women participants and did not conflict with their homemaking schedules or pose a risk for women traveling back home after dark

- **Promoting a non-judgemental environment** where beekeepers felt safe and comfortable sharing their experience, knowledge, and personal beekeeping information. Beekeepers were informed that they were not being tested on their ability or technical skill in using the prototype; rather the UX/UI designer was testing the actual design and user experience of the app for flaws, and that the beekeepers played a crucial role in improving the app and its functionality and localization.

These interviews further served as a great opportunity for establishing a personable connection with the beekeepers and while the focus was on women, men were included in interviews because the app will be made available for use by all beekeepers, regardless of gender. Including men also amplified the gender-specific differences that might affect adoption or use of the app, which enabled us to address them during iterations of the prototype. The AID-CSB project and participatory design model helps raise awareness among men too and facilitates perceptual shifts and cultural norms around women and technology that will give women access to the tech they need. Thus, effective development cycles require that men be a part of the solution.

3.2.2 | Uzbekistan: User Interviews

All 24 beekeepers participated in preliminary interviews to enable a strong understanding of what beekeeping is like in Uzbekistan, including:

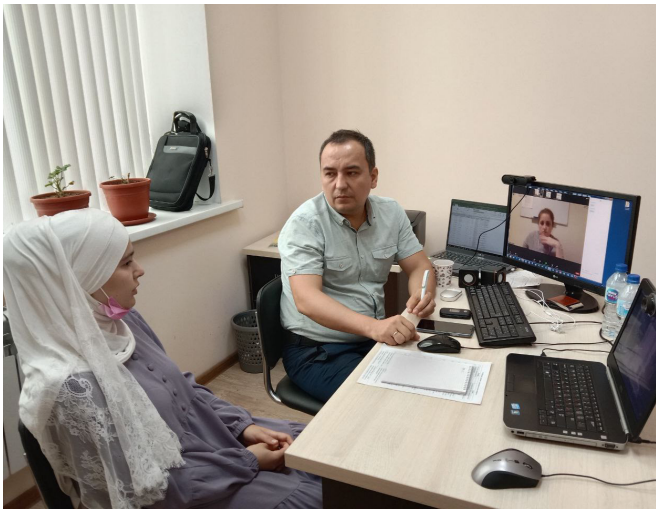
- personal beekeeping histories
- beekeeping practices
- record-keeping behavior
- challenges faced (local diseases/pests, gender-related)
- environment
- technology-based obstacles
- what products they sell to whom and how
- variables in beekeeping terminology and practices (hive types, queen species, threats, and weather
- what resources are currently available to them for improving their beekeeping knowledge (beekeeping mentors, organizations, internet, etc.)

Using the information provided by beekeepers during the initial one-on-one interviews, the UX/UI designer localized working prototypes to test specific app functionality and features with the same beekeeping participants, which were then translated into Uzbek and Russian.

3.2.3 | Ethiopia: Smartphone Training & Prototype Testing

Unlike Uzbekistan, Ethiopian beekeepers were only interviewed by the UX/UI designer once for prototype testing, given the challenge to meet with women beekeepers during the rainy season and out of respect for their time during this labor-intensive agricultural period. Therefore, in order to learn about beekeeping practices and challenges in Ethiopia, the *icipe* focal points interviewed beekeepers using a brief questionnaire prior to prototype testing. Furthermore, meetings were held with *icipe's* YESH project managers, and desk research was conducted by a HiveTracks data analyst. It was evident from the beekeeper questionnaire that smartphone training would be required prior to prototype testing, further described in section 4.2.2 below.

	# of participants	
Activity type	Tashkent	Bukhara
Preliminary interview	12	12
Prototype testing	9	8



Prototype testing was conducted across the three sites to test different components of the app:

- Hive-level Inspection
- Apiary and Hive Setup
- Apiary-level Hive Inspection

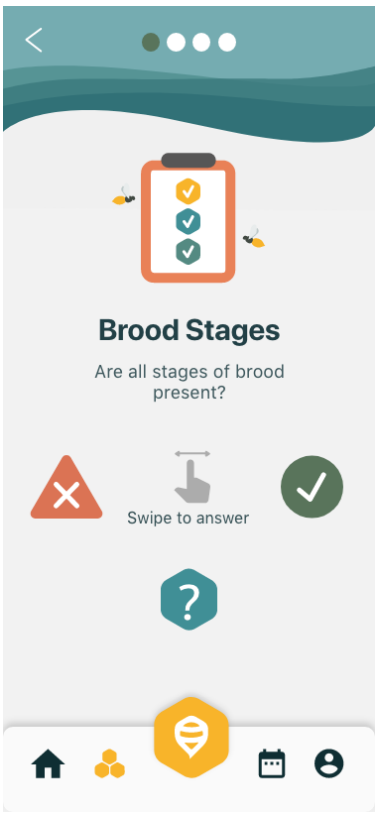
To best facilitate testing, the UX/UI designer worked with the YESH field operations manager, who served as translator and also navigated the prototype according to the instructions relayed by the women beekeeper participants (who did not have experience using a laptop). *icipe* focal points (older, men beekeepers serving as mentors) were also engaged for field assistance and additional application feedback. Poor internet connectivity created many difficulties and interruptions to the prototype-testing sessions. However, the YESH field operations manager was trained to conduct UX prototype sessions and was able to continue the testing process and document feedback when the internet proved too unstable for Zoom video connection. While testing conditions were not ideal, participants provided useful insight and feedback on how to improve the design, as well as validated the utility of the apiary-level inspection process.

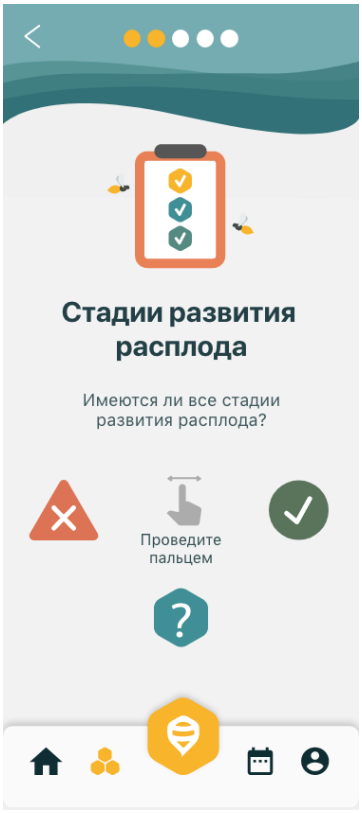
Top image: Top image: UX/UI designer conducts Uzbekistan user interview with a beekeeper and translator. (Credit: ICARDA). Middle left: Some participating beekeepers from Tashkent gather after preliminary interviews. Bottom left: Bukhara participants. Bottom right: A beekeeper in Bukhara participates in an interview with UX/UI designer. (Credits: ICARDA)

Ethiopian Participants

Activity type	East Gojjam/Hulet Eju	East Gojjam/Awabel	Awi/Guangua and Dangila
		# of participants	
Smartphone training	5	5	5
Prototype testing	5	5	3

Image left: Smartphone training with Ethiopian beekeepers. Images top right: Prototype testing partipants in Ethiopia. (Credits: icipe). Screens for the beekeeping inspection process in English and translated into Russian and Amharic for prototype testing. (Credits: HiveTracks).





4 | Results from User Interviews & Technology Co-design

4.1 | Results: Uzbekistan

4.1.1 | Beekeeping Season, Bloom Cycles

The season for Uzbek beekeepers typically starts in late March, when temperatures are above ten degrees Celsius (50 degrees Fahrenheit). However, actual start dates vary depending on weather, which is highly unpredictable in spring. After the season ends (in late October/November) the hives must be winterized and beekeepers prepare the hives to endure harsh winter conditions by medicating the bees to boost immunity and then covering the hives with a thick, quilt-like blanket. During the season, participating beekeepers visited their hives, on average, three to four times a week to inspect. Similar to North American practices, hives were inspected for disease and pest levels or infestation; brood and egg health and development; status of the queen; general population; bee behavior; food and honey supply. All beekeepers interviewed—except one—recorded these observations in paper journals and kept notes on each hive. Some recorded additional data during inspection, especially weather data, honey data, and bloom cycle information. In addition to keeping paper records, some kept these other types of information in their heads (especially schedules of what to do when).

Almost all beekeepers were very clear about what bloomed in their region and when, reflecting the long beekeeping traditions in each country and the historical knowledge passed from one generation to the next. Some venture out to investigate bloom cycles and some actually relocate their apiary based on their findings. One beekeeper mentioned that he moved bees every season because he believed this improved or at least maintained hive health. Other beekeepers do not move their apiaries because they know the bloom cycles so well and because they rely on this knowledge, they do not record bloom data either, as they presume it is unchanged (which may or may not be true). Understanding bloom cycles is important for two primary reasons. First, if bees are foraging on agricultural crops sprayed with agro-chemicals, or are attracted to the smells from nearby soda manufacturing plants but can't find a way to access the syrup, then they are more likely to be exposed to toxic chemicals and become more aggressive back at the hives. Second, just like the terroir of specific regions affects the taste of wine and the kind of grapes grown to produce it, so too are honey "notes" affected by region and season. Changing bloom cycles introduces uncertainty into the manufacturing and sales cycle, possibly impacting a producer's economic potential as it has in other parts of the world like France.[1] Some Uzbek beekeepers are hesitant or unwilling to share blooming information with other beekeepers as it is considered a secret, giving them a competitive advantage against other beekeepers. This influenced the design of the community data sharing planned in the app to protect beekeepers' trade secrets related to blooming periods while still providing useful information to beekeepers that a particular blooming cycle has begun.

4.1.2 | Challenges

The most pressing challenges for beekeepers generally were disease, pesticides or chemicals from nearby manufacturing plants or farms, and pests. Combatting the varroa mite, Foulbrood, and Nosemosis (nosema) were the top disease concerns.

1 Geert de Clercq, "French Beekeepers Expect the Worst Harvest in Seasons Due to Climate Change," Reuters, October 9, 2021, https://www.reuters.com/business/environment/french-beekeepers-expect-worst-harvest-decades-due-climate-change-2021-10-19/#:~:text=PARIS%2C%20Oct%2019%20(Reuters),prevented%20bees%20from%20producing%20honey

Pesticides were deeply concerning to all interviewees and composed a significant part of every interview. Not only do pesticides pose risks for hive death, but they also contaminate honey, which means that Uzbek beekeepers cannot meet the import standards of other countries, limiting sales channels and economic potential. Several beekeepers expressed the need for more and better quality laboratories for honey composition testing and help communicating the risks of pesticide use to farmers.

Presently, there is no countrywide communication network connecting beekeepers with farmers and so there are limited cross-sector conversations about pesticide use and its effects on local biodiversity, bees, and crops. Specifically, beekeepers would like to know when farmers spray. While there are limited opportunities to do so, conversations between some beekeepers and farmers are happening, but with mixed results. Since pesticides and other agro-chemicals do indeed improve yields, many farmers are reluctant to reduce or alter their use or stop using them, despite the consequences on pollinators and surrounding habitats. In Uzbekistan, there are efforts by the Food and Agriculture Organization (FAO) Support for Sustainable Development of Beekeeping project to provide beekeepers with pesticide warnings through a smartphone app called Arizor[2] that leverages data from the Plant Protection Agency on the type and timing of agricultural pesticide application. The app was shared publicly with beekeepers on 5 December and the project ended in December 2021 and was handed over to the Association of Beekeepers of Uzbekistan (ABU) for maintenance and use. Throughout 2021, AID-CSB met with this project to exchange lessons learned, explore synergies, and avoid duplication of efforts, and will continue to do so.

4.1.3 | Challenges Specific to Women

When asked about challenges specific to women beekeepers, interviewees remarked that beekeeping is physically demanding. Women beekeepers have to move heavy hive boxes to reposition hives for better access to forage and to extract honey, which is time-consuming and physically exerting. The responsibility of raising a family makes it difficult for beekeepers to balance caring for their bees with caring for their families as it is viewed as culturally unacceptable for women to stay at apiaries past dark in traditional households; thus, there is particular importance on the flexibility needed for improved timing of beekeeping practices.

Additionally, the importance of the one-on-one user interview approach was validated during mixed-gender beekeeper discussion groups at the final workshops in Uzbekistan, where men dominated the conversation and women felt less comfortable speaking up. In one-on-one user interviews with women, they were more comfortable and vocal to voice their opinions.

4.1.4 | Language and Application Development

Other important findings included differences in language and terminology. For example, the U.S. version of the app refers to pests and diseases as “stressors”; however, in Uzbek culture “stress” only makes sense in context to human beings. Uzbek beekeepers don’t apply the concept of stress to animals or insects, so this term needs to be replaced with a word like “threats.” While such linguistic nuance may seem minor, these differences can frustrate understanding of the app, which can affect the uptake and use of it. Consistency of language and iconography was another important feedback point that will affect future iterations of the user interface.

4.1.5 | Weather & Climate Change

The majority of beekeepers interviewed noted the increased unpredictability of weather in Uzbekistan. Though beekeepers check the weather forecast daily, conditions can change rapidly and beekeepers are not always available

2 Arizor.uz, (2021), https://play.google.com/store/apps/details?id=com.arizoruz.beekeeping_system

to prepare their apiaries for such drastic weather changes. Additionally, it is very hot during the summer months (Average July temperature in Bukhara is 100°F/37.7°C) and beekeepers reported that winters are increasingly mild. A few beekeepers noticed there is less snow now, which results in less water and blooming flowers in the spring months. Historical data validates that temperatures are rising in Uzbekistan at an average rate of 0.27°C per decade, yet there is no evidence of changes in precipitation rates.[3] The rising summer temperatures threaten hive health and productivity as hives can overheat, and water sources for bees are scarce in extreme temperatures.

The effects of climate change were clearly visible shortly before the final project workshops, as Tashkent experienced its worst dust storm on record due to drought.[4] When project staff visited a beekeeper's apiary a few days later, he expressed his concern about the potential effects of the dust storm on his honeybees' health and the quality of honey, but said would not know how harsh the consequences would be until he opened his hives in the spring.

4.1.6 | Communication

The AID-CSB project illuminates the importance of understanding how information travels within beekeeping communities and the ways that communicative culture impacts the flow of information. In Uzbekistan, the most common communication between beekeepers occurs in a large Telegram group to exchange information on markets, share beekeeping photos, ask questions, and sell honey and hive products. Beekeepers also communicate and access information through membership in beekeeping organizations and knowledgeable family members and mentors. Despite the grassroots-level organization of the Telegram group, several types of information (such as pesticide use) and key decisions (such as honey pricing) flow top-down. Details like this are important in order to maximize networks of people effectively, and they could also have significant impacts on adoption and use of the application.

4.2 | Results: Ethiopia

4.2.1 | Beekeeping Season, Bloom Cycles and Climate Change

Due to large regional differences in climate and geography in Ethiopia, the start and end of the beekeeping season depends on the location of the beekeeper. The sites of AID-CSB beekeepers in Amhara are roughly characterized by two seasons. After a rainy season from June to August/September, the flowering period begins. Just after, from September to October the major blooming period takes place with a maximal deviation of three weeks. The off-season, which is characterized by the dearth period, a time in which there is a shortage of nectar-producing flowers, lasts approximately until late March. The main flowering source at this time is Eucalyptus which can be insufficient for bee forage needs. Thus, proper dearth period management is one of the more important practices in Ethiopia, to ensure availability of sufficient water sources and to feed bees at the right moment. A sub-season described by a shorter flowering period takes place starting from April or May and lasts until June, but all flowering seasons are increasingly impacted by climate change and without successful forage, bees cannot reproduce, they become more aggressive (which impacts beekeeper safety), and ultimately, bee colonies die.

Unlike Uzbek beekeepers, Ethiopian beekeepers do not keep written records of hive inspections or plan out beekeeping tasks in advance. Hives may be identified by a number, their hive type,

3 "Current Climate: Climatology," Climate Change Knowledge Portal:Uzbekistan, The World Bank Group, (2021), https://climateknowledgeportal.worldbank.org/country/uzbekistan/climate-data-historical.

4 "Dust Blankets Tashkent," NASA Earth Observatory, November 5, 2021, https://earthobservatory.nasa.gov/images/149067/dust-blankets-tashkent

a certain color, their position in the apiary, or nothing at all. Building these habits will be critical to the successful adoption of the Beekeeper's Companion app. Despite differing from their current practices, beekeepers expressed the helpfulness of the app in recommending what to do next depending on selections made during the inspection process. To support unique identification of hives and data collection, *icipe* produced and distributed unique hive identities (IDs) for beekeeper use. To support unique identification of hives and data collection, *icipe* produced and distributed unique hive identities (IDs) for beekeeper use.

Blooming cycles in Ethiopia are well-researched and known on a country level, but not on a subnational level. The dissemination of knowledge on bloom cycles and best practices between research centers and beekeepers is a major challenge. While research centers are fairly aware about dominant plant species per region and their bloom periods, beekeepers rely mostly on their own intuition and sight to identify it. Supporting rural beekeepers by indicating when flowering periods start and end such that necessary actions can be performed at the appropriate time was noted as an essential solution to further Ethiopian beekeeping, along with information about pesticide application on nearby farms.

4.2.2 | Challenges and Opportunities

In Ethiopia, one of the main challenges to overcome is the gender digital divide, in which rural, low-income women are less likely to be able to access and use digital technologies. To better understand the baseline level of beekeepers' digital knowledge and plan project activities accordingly, a survey was conducted with the 15 beekeepers on their use and comfort using technology. Four women had never used a smartphone, and only two women felt 100% confident using a smartphone. However, all but two beekeepers actively used social media, which requires many of the same digital skills as the Beekeeper's Companion app.

"Supporting rural beekeepers by indicating when flowering periods start and end such that necessary actions can be performed at the appropriate time was noted as an essential solution to further Ethiopian beekeeping, along with information about pesticide application on nearby farms."

Considering these findings, an ICARDA intern developed and implemented smartphone training to build off beekeepers' existing knowledge and familiarity with similar concepts (e.g. social media and basic mobile phone functions such as sending a text message and making a call.) Skills required for the app were also included, such as taking a photo and video and signing in to an account. To build a comfortable learning environment, beekeepers were encouraged to bring a tech-savvy family member who could help provide extra support during the training, which included many peer-to-peer exercises. The benefits of this approach were two-fold; (1) the women beekeepers felt comfortable asking their family members more questions during the workshop and were willing to deep-dive into topics, and (2) these family members learned which skills were necessary for the app and could practice more with the beekeeper at home. Today, the beekeepers exchange beekeeping photos in a Telegram group, practicing their new skills and sharing information and experiences.

4.2.3 | Challenges Specific to Women

Beekeepers stated that the practice of catching swarming colonies is difficult for women. Additionally, as the subspecies of *Apis mellifera* bee in Ethiopia is more aggressive than their European or American counterparts, apiary visits

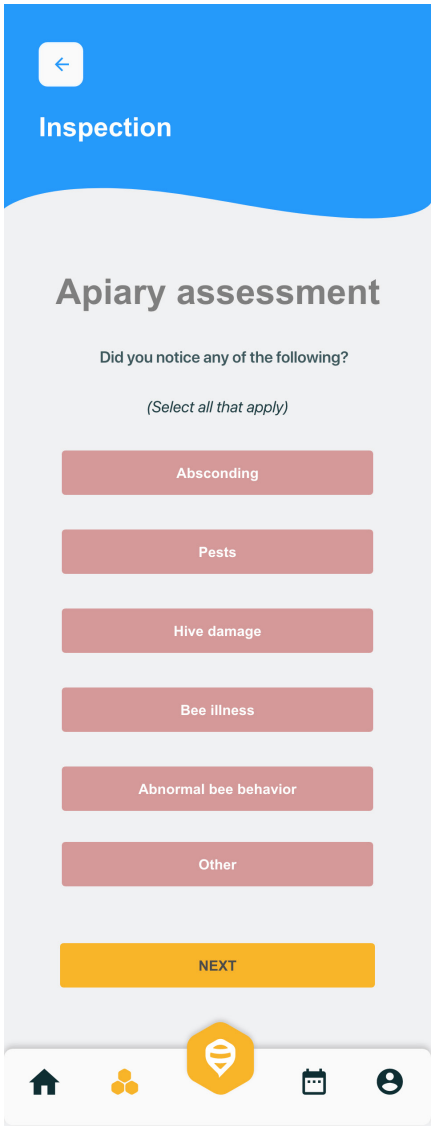
Traditional beekeeping practices in Ethiopia, in which hives are placed in trees often poses a gender barrier for women (Credit: Holeta Bee Research Centre)

and inspections need to be conducted in the evening hours when bees are more relaxed, but

doing so increases danger to women because their apiaries are often situated in remote areas. Furthermore, most hives are traditional and thus are located on tall trees, and some do not believe the practice of climbing the tree or otherwise accessing and controlling the beehive is an appropriate activity for women.

As with Uzbekistan, traditional gender roles do not encourage women to express their opinions or speak up. Similar to observations in Uzbekistan mixed-gender workshops, during the smartphone training (mixed-gender small groups of five to nine beekeepers with family members, and two field assistants), it was evident that some women beekeepers were not comfortable actively participating in group discussion. This challenge was anticipated and mitigated by including many peer-to-peer smartphone exercises in which women could practice directly with one another or family members, thus increasing their agency but also normalizing their use of technology. Nonetheless, this experience underscores the importance of one-on-one prototype testing sessions and highlights the broader barriers to inclusive and participatory design. For example, if the project team had chosen to conduct group feedback sessions on the prototype, they would have likely heard feedback from men beekeepers primarily, resulting in a skewed design of the app that suits the needs and preferences of men but not women beekeepers. By ensuring that beekeeper feedback on the prototype was sought one-on-one, AID-CSB was able to hear and include all voices and create a comfortable environment where women felt empowered to participate.

4.2.4 | Language and Application Development



A prototype screen for apiary-level inspection. (Credit: HiveTracks)

It became clear early in the UX design process that changes needed to be made in the app's

design for it to truly be localized. Most notably, the Beekeeper's Companion app was originally designed for hobbyist beekeepers who managed five hives or less. Project beekeepers often managed 20 to 100+ hives. An inspection process at

the individual hive-level did not meet user needs for the Ethiopian (as well as Uzbek) beekeepers who managed large apiaries and it became clear that an additional inspection process at the apiary-level will be a necessary addition to the application if it is to be beneficial to larger or commercial users in the future.

4.2.4 | Weather & Climate Change

Ethiopia hosts a wide range of climates with the most common being Savanna, hot desert, hot semi-arid and subtropical climates. As a result, beekeeping seasons vary substantially across the country. Anthropogenic climate change is an increasing challenge for beekeepers, as deforestation and degradation result in desertification of green areas, limiting the available nectar supply for honey bees, especially during the dearth period.

Contrary to Uzbek practices, many Ethiopian beekeepers do not check weather forecasts, mostly due to the lack of internet and technology access. Instead, weather is estimated and anticipated based on the current season. Consequently, this introduces uncertainty regarding the right timing of apiary visits and tasks to perform throughout the season, especially given the ways in which climate change is impacting weather and landscape.

4.2.5 | Communication

In contrast with the popular beekeeping Telegram group in Uzbekistan, in Ethiopia there are no mainstream peer-to-peer communication channels. Instead, trusted research centers (such as Holeta Bee Research Center) and projects (such as YESH) are the main channels for advisory services. However, given the estimated 1 million beekeepers in Ethiopia spread across the country, it is simply not possible for these centers to provide in-person advice and support to all beekeepers, emphasizing the need for alternative channels of communication and support, such as the Beekeeper's Companion app.

4.3 | Remote monitoring & data collection opportunity

Not having direct access to communication with beekeepers or fully understanding their operations and challenges makes it difficult for beekeepers to access the right information at the right time. The co-designed Beekeeper's Companion app unlocks the opportunity for local extension services, researchers, and project management to monitor and assess the data entered by beekeepers in an anonymized manner, if given consent. For example, the YESH project and Holeta Bee Research Center hope to use the app to scale the advisory support they provide, to reach more beekeepers at a greater frequency. Particularly in light of COVID-19 and the conflict in Northern Ethiopia, the app will provide a way to evaluate the challenges and successes of beekeepers when in-person visits are challenging.

Beekeepers, researchers, and agriculture stakeholders gather after the final project workshop in Tashkent (Credit: ICARDA).

5 | Recommendations & Opportunities

The AID-CSB project demonstrated that it is not only possible to conduct an inclusive, multi-country, multi-language agricultural UX/UI development project, it should be the new standard. There are several lessons learned and recommendations for other agriculture development projects and future AID-CSB work.

5.1 | Recommendations from lessons learned

Development partners and researchers wishing to conduct similar projects will benefit from AID-CSB's lessons learned on what worked, elaborated throughout the report and summarized below:

- Get to know project participants through **preliminary interviews**; this not only provides critical baseline information for technology development, but also builds relationships and trust
- Test your technology with the users through **prototype testing** by an experienced UX/UI designer to ensure the technology suits them and is adapted accordingly
- Leverage **1:1 interviews** to hear all voices; this technique is particularly helpful when collecting information from different genders and socioeconomic classes, as women and disadvantaged groups may be uncomfortable to share opinions in large group discussions
- Involve family members for **digital literacy training,** as trainees will be more comfortable to ask family members questions, and they can provide continued training and support at home
- **Manage expectations** and clearly communicate that because participants are co-designing the technology, they will experience many bugs and see imperfect versions of the technology
- Implement a **multi-step translation process** with both a professional translator and local beekeeping experts to ensure that text is not only translated, but fits local beekeeping terminologies and expressions, is gender-inclusive, and visually corresponds to the desired user action in the app design
- **Avoid designing technology to Western norms** by continuously iterating and clarifying that the technology is being made to suit participants' best beekeeping practices. For example, in the first round of desk research all Ethiopian flowering data was provided in the Gregorian calendar, as this is the international standard. However beekeepers use the Ethiopian calendar, and therefore the app needed to be designed as such
- **Reduce bias in technology design** by (1) identifying and acknowledging pre-existing societal biases and marginalized groups; (2) using real data when possible to avoid measurement bias, but when necessary, carefully leveraging proxy data; (3) ensure appropriate aggregation and evaluation measures within the technology; (4) ensure a focused scope (that the app is used for the intended purpose)

5.2 | Opportunities for Extending App Functionality and Use

Bringing use of the Beekeeper's Companion app to scale first requires that the solution itself is useful and desirable to beekeepers. By employing a co-design process, AID-CSB has ensured that user's needs are taken into consideration and, by way of verbal confirmation, the beekeepers in this project affirmed that the app will be helpful to them in managing their apiaries, enterprises, and mitigating the effects of climate change on their hives.

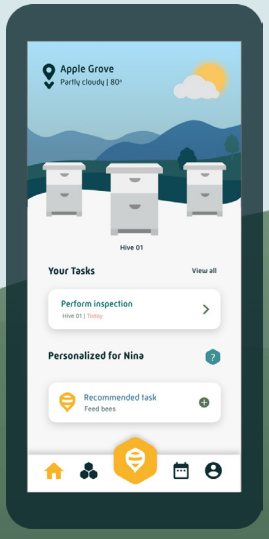
Identifying and collaborating with national stakeholders who are well-known and trusted by the beekeeping community was central to the localization and piloting of the app, and will continue to be critical for operational and financial sustainability and scaling up. Our local partners have indicated that the data collected by beekeepers (anonymized and aggregated) will be a great resource for extension services and research, hence incentivizing national partners to encourage beekeepers to use the app.

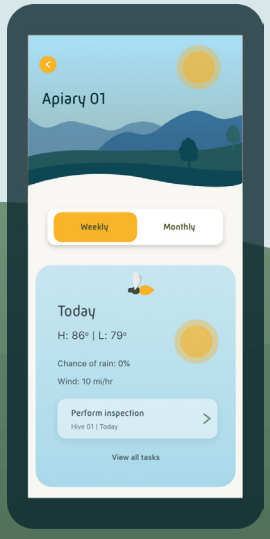
In the short-term, scaling will require demonstrating use and encouraging adoption of the app with existing and new beekeepers during the 2022 beekeeping season and ensuring other required inputs and supportive infrastructure are in place. During this time, the project team will be able to monitor data collection and provide in-person visits to support users. Aside from beekeeping equipment, the main input that beekeepers require to download the app is a smartphone. In Uzbekistan, smartphone ownership and use is the norm, even in rural areas; but in Ethiopia, basic mobile phones are the standard, particularly among low-income, rural women. Therefore, while equitable scalability in Uzbekistan is in theory possible without any additional inputs – given the app's offline functionality – in Ethiopia an short message service (SMS)-based version of the app would be needed to become available to beekeepers across the country.

In the long term, financial sustainability of the app is needed. In addition to exploring opportunities to localize app development and maintenance (thus reducing the total cost and increasing local ownership), there are three solutions that expand the functionality of the app and the data it produces, providing new revenue streams: traceability, a pollination service platform, and pesticide monitoring for planetary health.

5.2.1 | Authenticity and Traceability

Integrating traceability, including a transaction-based business model in combination with a mobile payment solution or other market-based approaches, enables market access for smallholder honey producers, including access to financial services. Honey traceability





is of particular interest globally, as it defends against economically motivated adulteration (EMA) of honey.[1] The availability of substitutes that create a similar flavor profile to raw honey coupled with a lack of certifications, standards, or basic traceability makes it easy to adulterate honey products. Honey "launderers" fool authenticity tests by making chemical modifications that make it difficult to trace where honey came from. Though testing has significantly improved since "Honeygate,"[2] much of the industry remains unregulated or the regulations in place, uninforced.

Presently, The U.S., United Kingdom, Canada, Presently, The U.S., United Kingdom, Canada, many European countries, as well as countries throughout South Asia, have established stricter standards of honey production, packaging, marketing, and traceability to ensure food safety standards. For example, in many of these countries, honey for export must carry certification that the level of pesticide residue and antibiotic levels are within permissible limits and that the honey does not contain genetically modified organism (GMO)-based products.

Honey and food traceability solutions can educate consumers on how pure and sustainably produced their product is. While building consumer trust is important, supporting producers that use Fair Trade and Organic production practices (which limit or eliminate pesticide use) through traceability is an even more important tactic because it can redress and generate awareness around climate issues related to pollinator declines.

There is potential to integrate new traceability features in the Beekeeper's Companion in future iterations of the app. Such features could improve access to markets and sales among smallholders, especially for those with access to channels of distribution beyond local markets and grocery stores or those that require certain standards before sale, while improving local habitats and conditions for bees to thrive.

5.2.2 | Pollination Service Platform

In their role as pollinators, honeybees improve the yields of crops, increasing the profit of farmers. Many countries have systems in which this is a paid service whereby farmers pay beekeepers to set up their hives near their fields. This is a possible way forward for the AID-CSB project, ensuring not only financial sustainability, but also a more inclusive ecosystem perspective, and perhaps opening channels of communication that foster a mutually beneficial exchange between farmers and beekeepers.

5.2.3 | Pesticide Monitoring for Planetary Health

Input-intensive agriculture, including the use of pesticides, challenges honey bees' health and decreases the pollination services that are vital for local agri-food systems and biodiversity. Better understanding the relationship between agricultural pesticides and honey bee health requires clear observation and documentation of honey bee symptoms, which will be possible when a new Symptom Checker feature is integrated into the app in 2022. This work will not only support beekeepers' incomes through reduced hive losses, but will also raise awareness about the links between pollinators and environmental health.

1 R. Fakhlaei, J. Selamat, A. Khatib, A. Razis, R. Sukor, S. Ahmad, and A. A. Babadi, "The Toxic Impact of Honey Adulteration: A Review," Foods, (2020), https://doi.org/10.3390/foods9111538.

2 D. Trotter, "U.S. Charges Five in Honey Anti-Dumping Probe," Reuters, February 20, 2013, https://www.reuters.com/article/usa-china-honey/u-s-charges-five-in-honeygate-anti-dumping-probe-idUSL1N0BKCRX20130220

6 | Conclusion

If smallholder farmers and beekeepers are expected to adopt climate-smart technology practices, they should be the first experts consulted. Data collection methods must respect the user's wide diversity of knowledge and challenges based on location, language, climate, gender, and digital skills.

This is particularly true when carrying out a gender-responsive participatory development process. Encouraged through one-on-one dialogue, women's input was at the center of the project, informing how the app interface, features, and gender-sensitive translations should be designed to best support their livelihoods as beekeepers. In addition to the direct support to beekeepers, the hive management practices facilitated through the app promotes pollination services to support healthy, biodiverse ecosystems critical to managing and mitigating climate change.

The AID-CSB project achieved critical first steps in 2021:

- addressing the gender digital divide through smartphone training
- gathering and integrating beekeepers' input through user interviews and prototype testing
- generating localized versions of the Beekeeper's Companion app for Uzbekistan and Ethiopia.

As the app is used by beekeepers for the honey harvesting seasons in 2022, the AID-CSB team will monitor incoming data and feedback regularly and make adjustments to further localize the app and support easy use. It will be crucial to monitor the use of the app through supporting data, including online metrics, and continuing the dialogue with women beekeepers to ensure that the app continues to satisfy user's needs.

At the same time, new features that are planned should continue the same gender-responsive participatory process. It is hoped that the structured process outlined throughout this report, underscoring reconciliation, empathy, and acceptance by both designer and user, sets the standard for future development projects, the beekeeping space, and projects in adjacent industries.

"Encouraged through one-on-one dialogue, women's input was at the center of the project, informing how the app interface, features, and gender-sensitive translations should be designed to best support their livelihoods as beekeepers."

Stakeholders have to work closely together to carefully evaluate the tension between localization and customization on the one hand and scalability on the other hand. It is essential that beekeepers feel heard and understood as they use the app, which their engagement over time will validate. At the same time, to be sustainable in the long-run, the app has to be maintainable across countries. Future opportunities, such as the marketplace for data-authenticated honey and pollination service outlined above, have the potential to pave the way towards local and global financial sustainability. The PPP approach chosen by the AID-CSB project seems well-suited to effectively solve this issue.

Finally, it will be key to understand the depth, quality, and frequency of data that can be collected while safeguarding the users' privacy, as it has the potential to enable and influence myriad new data-driven policies that protect pollinators and local ecosystems across Uzbekistan and Ethiopia. In doing so, it would become a beacon of smart technology use that protects the people, including vulnerable groups, and the environment alike.

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