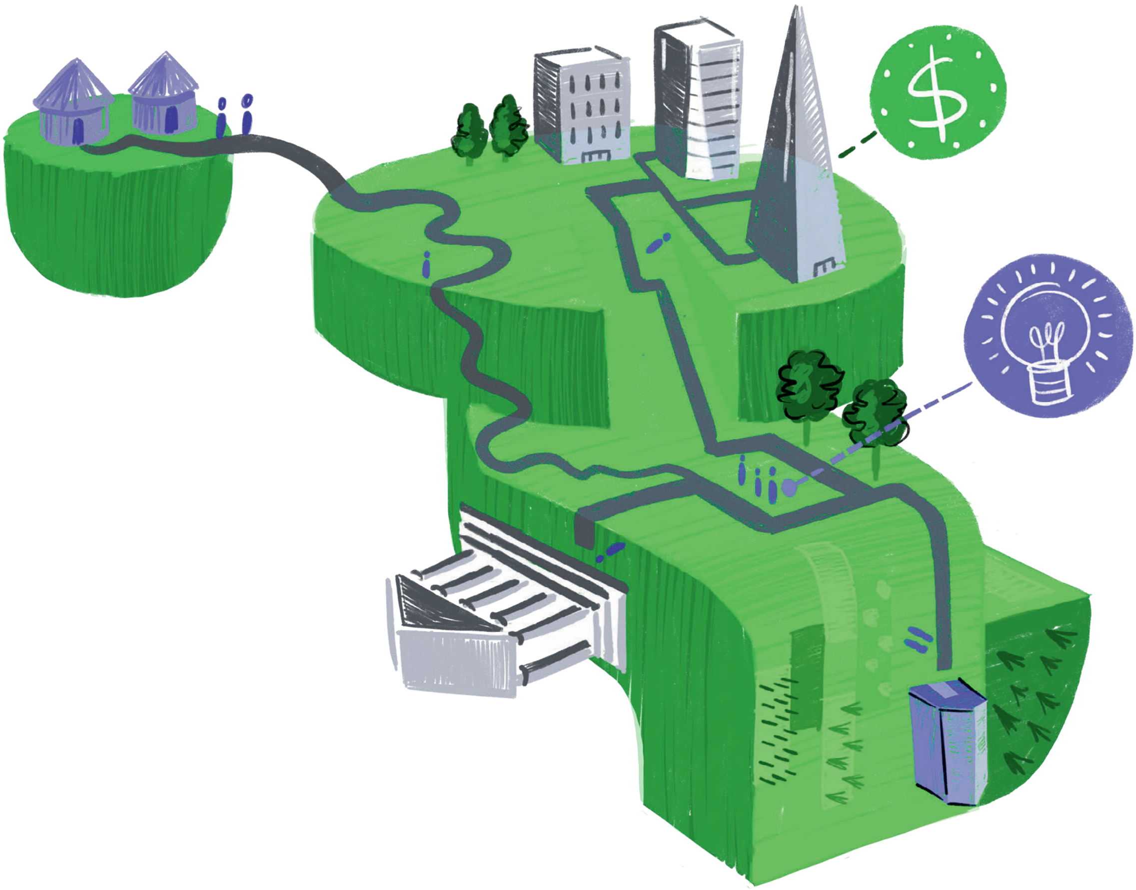


STEPPING UP SCIENCE-POLICY ENGAGEMENT TO ACCELERATE CLIMATE ACTION IN FOOD SYSTEMS

LESSONS ACROSS SCALES

Dhanush Arayamparambil Dinesh

STEPPING UP SCIENCE-POLICY ENGAGEMENT TO ACCELERATE CLIMATE ACTION IN FOOD SYSTEMS:

LESSONS ACROSS SCALES

Dhanush Arayamparambil Dinesh

ISBN: 978-94-6458-087-7

Layout: Laura R Bidder
Printing: Ridderprint

STEPPING UP SCIENCE-POLICY ENGAGEMENT TO ACCELERATE CLIMATE ACTION IN FOOD SYSTEMS:

LESSONS ACROSS SCALES

Intensivering van wetenschap-beleid betrokkenheid om klimaatactie in voedselsystemen te versnellen: lessen dwars door schalen heen

(met een samenvatting in het Nederlands)

Proefschrift

ter verkrijging van de graad van doctor aan de
Universiteit Utrecht
op gezag van de
rector magnificus, prof.dr. H.R.B.M. Kummeling,
ingevolge het besluit van het college voor promoties
in het openbaar te verdedigen op

vrijdag 11 maart 2022 des ochtends te 10.15 uur

door

Dhanush Arayamparambil Dinesh

geboren op 31 juli 1986
te Trivandrum, India

Promotor:

Prof. dr. P.P.J. Driessen

Copromotoren:

Dr. J.M. Vervoort
Dr. D.L.T. Hegger

TABLE OF CONTENTS

Table of Contents 5

List of figures 10

List of tables 11

SUMMARY 13

SAMENVATTING 17

CHAPTER 1: Introduction

1.1 Science-policy interactions, interfaces and engagement in the context of climate change 23

1.2 Climate change, agriculture and food security 27

1.3 Science-policy engagement to accelerate a transformation in food systems: main challenges and knowledge gaps 28

1.4 Research aim, questions and relevance 29

1.4.1 Research aim and questions 29

1.4.2 Societal relevance 32

1.5 Research design, selected case study and methods 33

1.5.1 Case study 33

1.5.2 Data collection and methods 35

1.5.3 Data analysis 35

1.5.4 Research ethics and positionality 36

1.6 Outline of the dissertation 36

CHAPTER 2: Facilitating change for climate-smart agriculture through science-policy engagement

2.1 Introduction 41

2.2 Contextualisation of programme theory 44

2.3 Methods 46

2.4 Results 47

2.4.1 Navigate towards specific points of leverage 48
2.4.2 Allocate resources in three thirds 48
2.4.3 Join in external processes 49
2.4.4 Use research products to build scientific credibility 49
2.4.5 Sustain co-learning throughout policy engagement and implementation 50
2.4.6 Tackle power and influence 50
2.4.7 Invest in, and monitor, capacity enhancement 51
2.4.8 Mainstream higher-level goals 51
2.4.9 Create mechanisms for internal learning 51
2.4.10 Communicate strategically and actively 52
2.4.11 Explanatory factors for successful science-policy engagement 52
2.4.12 Challenges in science-policy engagement efforts 53
2.4.13 Quantitative analysis and contextualisation of principles 53
2.5 Discussion 55
2.5.1 Engagement 56
2.5.2 Evidence 57
2.5.3 Outreach 58
2.6 A revised and improved programme theory 59
2.7 Conclusion 60
CHAPTER 3: Learning from failure at the science-policy interface for climate action in agriculture
3.1 Introduction 65
3.2 Explanatory framework 67
3.3 Methods 68
3.4 Results 70
3.4.1 Knowledge generated is not perceived as credible 70
3.4.2 Knowledge generated is not salient 70
3.4.3 Knowledge generated is not legitimate 71
3.4.4 Engagement process lacked appropriate intermediaries 72

3.4.5 Adverse power dynamics 72
3.4.6 Lack of institutional capacity 73
3.4.7 Inductively derived fail factors in science-policy engagement 73
3.4.8 Fail factors contextualised in examples 75
3.5 Discussion 77
3.5.1 Credibility, salience and legitimacy 77
3.5.2 Institutional arrangements and capacity 78
3.5.3 Navigating power dynamics 80
3.5.4 Funding uncertainties 81
3.6 Failing intelligently at the interface between science and policy 81
3.7 Conclusions 82

CHAPTER 4: A changing climate for knowledge generation in agriculture: Lessons to institutionalise science-policy engagement

4.1 Introduction 87
4.2 Conceptual approach and methods 90
4.2.1 Conceptual approach: institutional analysis for AR4D 90
4.3 Methods 91
4.4 Results 92
4.4.1 Accountability 92
4.4.2 Use of boundary objects 94
4.4.3 Participation across the boundary 95
4.4.4 Mediation and a selectively permeable boundary 96
4.4.5 Translation 97
4.4.6 Coordination and complementary expertise 98
4.4.7 Additional success conditions identified 99
4.5 Discussion 101
4.5.1 Success conditions for institutionalising efforts to enhance salience, credibility and legitimacy 101
4.5.2 Creating an environment for 'enlightened' boundary work 102

4.5.3 Opportunities for institutional analysis 104
4.6 Conclusion 105

CHAPTER 5: Enacting theories of change for food systems transformation under climate change

5.1 Introduction 109
5.2 A theory of change to catalyse a transformation in food systems under climate change 111
5.3 Methods 113
5.4 Results 114
5.4.1 Biggest issues facing the food knowledge and innovation system 114
5.4.2 Priorities across themes 115
5.4.3 Empowering farmer and consumer organisations, women and youth 116
5.4.4 Digitally enabled climate-informed services 116
5.4.5 Climate-resilient and low-emission practices and technologies 117
5.4.6 Innovative finance to leverage public and private sector investments 117
5.4.7 Reshaping supply chains, food retail, marketing and procurement 118
5.4.8 Fostering enabling policies and institutions 118
5.4.9 Factors that limit interaction among different players in the system 118
5.4.10 Priorities for food systems transformation 119
5.5 Discussion 121
5.5.1 Unpacking priorities for food systems transformation 121
5.5.2 Actioning priorities for food systems transformation – Next Steps 123
5.6 Conclusion 125

CHAPTER 6: Conclusion

6.1 Conclusions and reflections 129
6.1.1 Factors for fruitful science-policy engagement 129
6.1.2 Lessons to make science-policy engagement work across scales 133

6.1.3 Implications for science-policy engagement research 135

6.2 Contributions to CCAFS and beyond 136

6.3 Directions for SPE practitioners and researchers 137

6.4 Reflections on methods and recommendations for further research 139

6.5 Science-policy engagement for climate action in agriculture and food: final observations 141

ENDNOTES

References 145

Appendices 163

Acknowledgements 173

About the author 175

List of figures

1.1 Main Research Question (MRQ) and Subsidiary Research Questions (SRQs) of this dissertation 32

2.1 Average score of each principle by different scales of case studies 54

2.2 Programme theory for effective science-policy engagement 60

3.1 Steps for failing intelligently in science-policy engagement for climate action in agriculture 82

5.1 Theory of change for transforming food systems under climate change, based on Campbell et al. (2018) 112

5.2 Inductively categorized priorities for the food knowledge and innovation system 115

5.3 Most important themes to catalyse a transformation in food systems 115

List of tables

1.1	Climate change through the CGIAR reforms	34
1.2	Subsidiary Research Questions and methods applied	35
1.3	Outline of the dissertation	37
2.1	Principles underlying the CCAFS programme theory explained	44
2.2	Comparison of the three thirds principle against the key components of knowledge systems for sustainable development (Cash et al., 2003)	55
3.1	Explanatory framework for failures in science-policy engagement efforts	68
3.2	Inductive categorisation of challenges encountered in demonstrating credibility	70
3.3	Inductive categorisation of challenges encountered in achieving salience	71
3.4	Types of intermediaries engaged and their roles	72
3.5	Inductive categorisation of challenges in navigating adverse power dynamics in science-policy engagement	73
3.6	Empirical fail factors in science-policy engagement efforts as a specification or addition to hypothetical fail factors	74
3.7	Examples of failed science-policy engagement efforts identified through interviews with CCAFS management	76
4.1	Framework for examining programme efforts to enhance salience, credibility and legitimacy (Adapted from Cash et al. 2002)	90
4.2	Success conditions and lessons for institutionalisation	102
5.1	Priorities for research and action under a new regime for innovation	119
6.1	Theoretical contributions from science-policy engagement at multiple scales	130
6.2	Key insights on SPE working across scales	133
6.3	Conditions to enhance salience, credibility and legitimacy across scales	135

Summary

Our food systems contribute a third of global anthropogenic greenhouse emissions, and in the face of accelerating climate change the livelihoods of over 500 million small-scale producers are at risk. Clearly, food systems form part of the problem and yet need to be part of the solution if efforts to combat climate change are to succeed. This can only occur if science informs policy and practice such that transformative actions are taken within the sector. This is why research and practice around science-policy interactions is so crucial, yet efforts have fallen short in the four decades since this notion was first put forward. Efforts must be accelerated whereby science-led policy drives fruitful outcomes for society and the climate. This is where the concept of Science-Policy Engagement (SPE), the set of strategies and actions undertaken to realise productive outcomes for climate and society, becomes significant. In order to step up SPE efforts to accelerate climate action in food systems, lessons are needed on what works, what doesn't, how good practices can be institutionalised and how efforts can be taken to scale. This dissertation seeks to answer these questions.

Within the literature on science-policy interactions, the seminal paper by Cash et al. (2003) identified the enhancement of salience, credibility, and legitimacy as success conditions for knowledge generation. Applying these success conditions to successful science-policy engagement case studies and from drawing on a portfolio of projects of the CGIAR Research Program on Climate Change, Agriculture and Food Security, (CCAFS), I identified several factors for the design of research projects which enhance the Cash et al. (2003) conditions to deliver positive outcomes from SPE efforts. These success factors have been developed into the three-thirds principle. This principle involves a third of the research effort being focused on engagement, or engaging stakeholders to demand and co-develop knowledge to ensure their saliency and legitimacy. Another third of the research effort focuses on the production of evidence that is salient, credible, and legitimate, and the final third focuses on outreach, where outreach involves communications and building capacity to enhance uptake. Applying the three-thirds principle and the underlying success factors in the design of research projects can help drive successful outcomes from science-policy engagement. The large-scale application of the principle requires incentives for researchers, with greater emphasis placed by research managers on achieving positive societal outcomes.

While such success factors are important for designing science-policy engagement efforts, I also sought to ascertain whether the absence of the Cash et al. (2003) success conditions (salience, legitimacy and credibility) can cause SPE efforts to fail. Taking a programme-level

perspective, I found that while the absence of salience was indeed a fail factor, lack of credibility and legitimacy did not appear as fail factors in the CCAFS context. In addition to the lack of salience, the lack of institutional capacity, adverse power dynamics, and funding uncertainties were the other empirically derived fail factors identified from the CCAFS programme. To address these fail factors, I developed an approach to 'fail intelligently' by planning for failure, minimizing risks in efforts, effective design of efforts, making failures visible, and learning from failures.

Cash et al. (2002) proposed six success conditions for organisations working at the science-policy interface, these were: 1) increased accountability, 2) use of boundary objects, 3) participation across the boundary, 4) mediation and a selectively permeable boundary, 5) translation, and 6) coordination and complementary expertise. I sought to ascertain the applicability of these success conditions in the context of the CGIAR's response to climate change, being the international network responsible for agricultural research for development. The applicability of these success conditions were indeed confirmed, alongside two additional success conditions – effective leadership and the presence of incentives, which were identified as key contributions to institutionalise science-policy engagement efforts within the CGIAR's response to climate change. These findings can also help other organisations institutionalise SPE in their response to climate change.

The above-mentioned efforts at the project, programme, and organisational scales show the importance of a conducive and enabling environment for science-policy engagement efforts to be undertaken. Therefore, I focused on the knowledge and innovation system for food and agriculture, in the context of climate change, to identify priorities as part of a Theory of Change to catalyse transformation in food systems. Such priorities can enable meaningful and impactful SPE efforts across the system. The priorities for such a transformation are: 1) Empowering farmer and consumer organisations, women and youth; 2) Digitally enabled climate-informed services; 3) Climate-resilient and low-emission practices and technologies; 4) Innovative finance to leverage public and private sector investments; 5) Reshaping supply chains, food retail, marketing and procurement; 6) Fostering enabling policies and institutions; 7) Knowledge transfer; 8) Addressing fragmentation in knowledge and innovation systems; and 9) Ensuring food security. In actioning these priorities, SPE has a major role to play by realising outcomes and impact in these priority areas. Regarding specific topics for transformation (i.e., priorities 1 – 6 and 9), there is a strong opportunity for knowledge to be generated in alignment with the findings around success and fail factors. In addition, two of the priorities (7 and 8) concern knowledge production and transfer, and there is an opportunity here to focus on specifically improving science-policy engagement in order to enable the other priorities.

These findings shed light on what works, what doesn't work, how efforts can be institutionalised, and how efforts can be taken to scale SPE in food systems in response to climate change. Crucial to fruitful science-policy engagement across scales is the interaction amongst these scales, which can help foster a more concerted effort across the knowledge and innovation system. In the face of accelerating climate change, system-wide efforts must be made to reorient and reform the old, develop the new, and phase out parts of the system which are redundant.

Samenvatting

Onze voedselsystemen dragen voor een derde bij aan de wereldwijde antropogene uitstoot van broeikasgassen. In het licht van de versnellende klimaatverandering staat het levensonderhoud van meer dan 500 miljoen kleinschalige producenten op het spel. Het is duidelijk dat voedselsystemen een deel van het probleem zijn, maar dat zij tegelijkertijd ook een deel van de oplossing zouden moeten zijn, teneinde de inspanningen om de klimaatverandering te bestrijden te laten slagen. Dat kan alleen als de wetenschap het beleid en de praktijk zo informeert dat er transformerende acties worden ondernomen binnen de voedselsector. Om die reden zijn onderzoek en praktijk rondom interacties tussen wetenschap en beleid cruciaal. De resultaten van dergelijke interacties zijn in de vier decennia sinds dit idee voor het eerst naar voren werd gebracht vaak teleurstellend geweest. De inspanningen om wetenschap en beleid beter bij elkaar te betrekken moeten worden versneld, zodat door wetenschap onderbouwd beleid kan leiden tot succesvolle resultaten voor de samenleving en het klimaat. Dit maakt het concept Science-Policy Engagement (SPE), de reeks strategieën en acties die worden ondernomen om productieve resultaten voor klimaat en samenleving te realiseren, belangrijk. Om SPE te intensiveren, teneinde klimaatactie in voedselsystemen te versnellen, zijn lessen nodig over wat werkt en wat niet, hoe goede praktijken kunnen worden geïnstitutionaliseerd en hoe inspanningen kunnen worden opgeschaald. Dit proefschrift probeert deze vragen te beantwoorden.

Binnen de literatuur over interacties tussen wetenschap en beleid is het artikel van Cash et al. (2003) over de verbetering van de relevantie (*salience*), de geloofwaardigheid (*credibility*) en de legitimiteit (*legitimacy*) als succesvoorwaarden voor het genereren van kennis geïdentificeerd. Door deze succesvoorwaarden toe te passen op succesvolle casestudy's op het gebied van wetenschap en beleid en door gebruik te maken van een portfolio van projecten van de CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), identificeerde ik verschillende factoren voor het ontwerp van onderzoeksprojecten die zo goed mogelijk voldoen aan de voorwaarden van Cash et al. (2003), teneinde tot positieve resultaten van SPE-inspanningen te komen. Een belangrijke succesfactor is het ‘drie-derde-principe’. Dit principe houdt in dat een derde van de onderzoeksinspanningen gericht dient te zijn op betrokkenheid of het betrekken van belanghebbenden bij het eisen en mede ontwikkelen van kennis om hun relevantie en legitimiteit te waarborgen. Een ander derde van de onderzoeksinspanningen is gericht op het produceren van bewijs dat relevant, geloofwaardig en legitiem is. Het laatste derde deel richt zich op verspreiding, waarbij verspreiding betrekking heeft op communicatie en het opbouwen van capaciteit om de toepassing van het onderzoek te vergroten. Het toepassen van

het ‘drie-derde-principe’ en de onderliggende succesfactoren bij het ontwerpen van onderzoeksprojecten kan eraan bijdragen om succesvolle resultaten van betrokkenheid tussen wetenschap en beleid aan te drijven. De grootschalige toepassing van het principe vereist aansporing van onderzoekers, waarbij onderzoekmanagers meer nadruk leggen op het behalen van positieve maatschappelijke resultaten.

Dergelijke succesfactoren zijn belangrijk voor het ontwerpen van inspanningen op het gebied van betrokkenheid tussen wetenschap en beleid. De vraag komt echter op, of de *af*wezigheid van de succesvoorwaarden van Cash et al. (2003) (relevantie, legitimiteit en geloofwaardigheid) ertoe kunnen leiden dat SPE-inspanningen mislukken. Vanuit een analyse van het programmaniveau ontdekte ik dat de afwezigheid van relevantie inderdaad een faalfactor was. Gebrek aan geloofwaardigheid en legitimiteit bleken daarentegen geen faalfactoren te zijn in de CCAFS-context. Naast het gebrek aan relevantie waren het gebrek aan institutionele capaciteit, ongunstige machtsdynamiek en financieringsonzekerheden andere empirisch afgeleide faalfactoren in het CCAFS-programma. Om deze faalfactoren aan te pakken heb ik een aanpak ontwikkeld om 'intelligent te falen', door te plannen voor mislukking, risico's bij inspanningen te minimaliseren, inspanningen effectief te ontwerpen, mislukkingen zichtbaar te maken en van mislukkingen te leren.

Cash et al. (2002) presenteerden in hun artikel zes succesfactoren voor organisaties die werkzaam zijn op het raakvlak tussen wetenschap en beleid, namelijk: 1) verhoogde verantwoordelijkheid, 2) gebruik van grensobjecten, 3) participatie over de grens van wetenschap en beleid, 4) bemiddeling en een selectief doorlaatbare grens, 5) vertaling, en 6) coördinatie en complementaire expertise. Ik heb geprobeerd de toepasbaarheid van deze succesvoorwaarden vast te stellen in de context van de reactie van de CGIAR op klimaatverandering. De CGIAR is het internationale netwerk dat verantwoordelijk is voor landbouwonderzoek voor ontwikkeling. De toepasbaarheid van deze succesvoorwaarden werd inderdaad bevestigd, naast twee aanvullende succesvoorwaarden, effectief leiderschap en de aanwezigheid van aansporingen, die werden geïdentificeerd als belangrijke bijdragen aan het institutionaliseren van inspanningen voor betrokkenheid tussen wetenschap en beleid in het kader van de reactie van de CGIAR op klimaatverandering. Deze bevindingen kunnen ook andere organisaties helpen om SPE te institutionaliseren in hun reactie op klimaatverandering.

De bovengenoemde inspanningen op project-, programma- en organisatieniveau tonen het belang van een gunstige en stimulerende omgeving voor het leveren van inspanningen op het gebied van betrokkenheid tussen wetenschap en beleid. Daarom heb ik me gericht op het kennis- en innovatiesysteem voor voedsel en landbouw, in de context van klimaatverandering, om prioriteiten te identificeren als onderdeel van een ‘Theory of Change’ gericht op het versnellen van transformaties in voedselsystemen. Dergelijke prioriteiten kunnen zinvolle en impactvolle SPE-inspanningen in het hele systeem mogelijk maken. De prioriteiten voor een dergelijke transformatie zijn: 1) Positie versterking van landbouw- en consumentenorganisaties, vrouwen en jongeren; 2) Digitaal toegankelijke klimaatgeïnformeerde diensten; 3) Klimaatbestendige en emissiearme activiteiten en technologieën; 4) Innovatieve financiering om investeringen van de publieke en private sector te stimuleren; 5) Hervormen van toeleveringsketens, levensmiddelendetailhandel, marketing en inkoop; 6) Bevorderen van faciliterend beleid en instellingen; 7) Kennisoverdracht; 8) Het aanpakken van versnippering in kennis- en innovatiesystemen; en 9) Zorgen voor voedselzekerheid. Bij de uitvoering van deze prioriteiten is voor SPE een belangrijke rol weggelegd door de verwezenlijking van resultaten en effecten op deze prioritaire gebieden.. Met betrekking tot specifieke onderwerpen voor transformatie (d.w.z. prioriteiten 1 - 6 en 9) is er een grote kans om kennis te genereren in overeenstemming met de bevindingen rondom succes- en faalfactoren. Daarnaast hebben twee van de prioriteiten (7 en 8) betrekking op kennisproductie en -overdracht, en ligt hier een kans om te focussen op het specifiek verbeteren van de betrokkenheid tussen wetenschap en beleid en hierdoor een focus op de andere prioriteiten mogelijk te maken.

Deze bevindingen tonen aan wat werkt, wat niet werkt, hoe inspanningen kunnen worden geïnstitutionaliseerd en hoe inspanningen kunnen worden geleverd om SPE in voedselsystemen op te schalen in reactie op klimaatverandering. Cruciaal voor een succesvolle betrokkenheid tussen wetenschap en beleid dwars door schalen heen is de interactie tussen deze schalen, die kunnen bijdragen aan een meer gecoördineerde inspanning in het gehele kennis- en innovatiesysteem. In de aanwezigheid van de versnellende klimaatverandering moeten systeembrede inspanningen worden geleverd om het oude systeem te heroriënteren en te hervormen, het nieuwe te ontwikkelen en overbodige delen van het systeem af te schaffen.

CHAPTER 1

INTRODUCTION

1.1 Science-policy interactions, interfaces and engagement in the context of climate change

In the four decades since the 1979 World Climate Conference, when the notion of 'science for policy' was first put forward in the context of climate change (Agrawala, 1999), the interaction between science and policy has continued to garner international attention as part of the global response to climate change. Over this period, there has been a growing emphasis on the interaction between science and policy as political processes, actors, and institutions seek a science-based response to climate change, which in turn requires changes to how knowledge is produced and organised (Leroy et al., 2010).

To keep climate change within acceptable limits, and to know how and when to adapt, policymakers require scientific input to make their decisions. Interactions among science, society, and politics can help underpin policy shifts (Leroy et al., 2010). However, as simple as this premise sounds, it has been far from easy, with progress held back due to a number of constraints, including the established models of interaction, the priority given to retaining the legitimacy and credibility of science, failure to provide inputs in a timely manner, lack of strategic development and use of knowledge, and the challenge of reconciling demand with the supply of knowledge (Agrawala, 1999; Sundqvist et al., 2018; Van Enst et al., 2014). Faced with these limitations, among others, effective climate action has not accelerated at the pace needed, and the most recent report from the Intergovernmental Panel on Climate Change (IPCC, 2021) has been unequivocal on human-induced climate change and warns of drastic consequences. The UN Secretary-General labelled the report *"code red"* for humanity, while youth activist Greta Thunberg called political efforts to resolve climate change *"30 years of blah blah blah."* To step up to the scale of the challenge, a new mission orientation is needed across the global economy which mobilises the ambition, collaboration, and investment needed across public and private sectors to solve the problem (Mazzucato, 2021). Mazzucato calls for a new approach to purpose-driven partnership, and, in this context, it becomes important to take stock of efforts thus far and rethink how science can better inform policy and deliver positive outcomes for society and the climate.

To address challenges faced in the interaction between science and policy, Science-Policy Interfaces (SPIs) have emerged as a major area of scholarly research and action in the context of sustainable development (Cash et al., 2003; Vellinga et al., 1995). Van den Hove has defined SPIs as *"social processes which encompass relations between scientists and other actors in the policy process, and which allow for exchanges, co-evolution, and joint construction of knowledge with the aim of enriching decision-making"* (van den Hove, 2007). These processes are broad, ranging from systematic assessments (Cash and Clark, 2001; Maas et al., 2021) and bodies specifically set up for interfaces – such as the Intergovernmental Platform for Biodiversity and Ecosystem Services (Koetz et al., 2012), to providing technical inputs that inform decision-making (Clark et al., 2016a), knowledge brokering (Turnhout et al., 2013), joint knowledge production (Hegger and Dieperink, 2014), and the development of tools and resources (Hegger et al., 2020). Active efforts are needed to construct and manage these processes, mechanisms, organisations, tools, and resources, which have been referred to as ‘boundary work’ (Clark et al., 2016a). Different types of boundary work, such as informing decisions, negotiations, and the creation of enlightened spaces have also been identified (Clark et al., 2016b).

Research on science-policy interfaces has seen these processes, mechanisms, organisations, tools, and resources being studied in various contexts and at differing scales. The seminal paper by Cash et al., (2003) focused on the quality of SPI processes and led to the identification of enhancing salience, credibility, and legitimacy in knowledge generation as success conditions to improve SPIs. This involves ensuring that the knowledge generated addresses the actual needs of users, is credible enough to inspire action, and legitimately captures diverse views. These success conditions have formed the foundation for SPI research and much work has been done by scholars to further examine these attributes.

Scholarly work has identified several challenges that deter efforts to ensure the *salience* of knowledge generated. These range from a lack of user orientation in the research to the insufficient engagement of multiple disciplines and networks (van den Hove, 2007). Similarly, ensuring *credibility* in the knowledge produced also comes with challenges, including communicating uncertainty and dissent from users – but this can be navigated by efforts to build trust (Lacey et al., 2018). *Legitimacy* is key to whether knowledge generated is accepted or not, as this is beyond scientific rigour and relates to social acceptability as a result of the inclusion of diverse views (Leroy et al., 2010). Legitimacy can be enhanced by incorporating stakeholder perspectives from the outset (Stringer and Dougill, 2013), effective boundary work (Bednarek et al., 2018; Dunn and Laing, 2017), joint knowledge production (Hegger and Dieperink, 2014), and ‘iterativity’ in the knowledge generation process (Dilling and Lemos, 2011). Cash et al., (2002) indicate how these success conditions can be institutionalised in organisations that are responsible for knowledge generation (Cash et al., 2002). However, efforts to maximise these success conditions come with trade-offs in that they cost time, compromise quality when done quickly, might enhance complexity or over-simplify messages, and focus on policy demand-driven knowledge as opposed to that driven by research needs (Sarkki et al., 2014).

Studies on science-policy interfaces are limited in the food and agriculture sector, although early papers which provide the foundation for SPI research come from experiences in this sector. Similarly, much of the scholarly work has emerged from the Global North and lessons from the Global South are limited (Clark et al., 2016a). However, it has been noted that SPIs can be crucial to step up to the challenges at the intersection of climate change, agriculture and food security (Hainzelin et al., 2021). Moreover, Cash and Belloy (2020) have noted the need for greater understanding of cross-scale interactions for more ambitious action to address environmental problems (Cash and Belloy, 2020). Therefore, in addition to addressing sectoral and regional gaps in studies on science-policy interfaces, research at different scales can also help advance action. Such efforts will address an operational misfit in SPIs in its ability to reach desired target groups; more specifically, scientific knowledge may be insufficiently phrased in practical terms or may be available at the wrong time (too early or too late). These efforts need to take place within a highly politicised environment for knowledge production and use (Meadowcroft, 2007) and must transcend disciplinary boundaries in order to provide solutions.

While science-policy interfaces focus on the interactions between science and policy to enrich decision making (van Enst, 2018), the term itself captures a complex and fragmented reality involving several different mechanisms, strategies, and processes. SPIs cannot simply happen, as the shifts needed for climate action are inherently political and not purely technical or administrative. This means efforts should be made to engage actively with society (Meadowcroft, 2007) and in this context various people and institutions have coined the notion of Science-Policy Engagement (SPE) as crucial to highlighting the need for sustained two-way interaction between science and policy. SPE is an integral part of SPI, one that has received little attention in scholarly research, although it is used extensively by the practitioner community. Many universities, research institutions, and think-tanks are setting up SPE units and strategies to inform policy decisions. One example is the Stockholm Environment Institute, which has undertaken a comprehensive review of science-policy engagement efforts (Kuylenstierna et al., 2021). The University of Oxford is also increasing its focus on policy engagement and defines it as *"an umbrella term describing the many ways that researchers and policymakers connect and explore common interests at various stages in their respective research and policymaking processes. From informal enquiries to formal inquiries, in consultation or sustained collaboration, policy engagement enables researchers and policymakers to improve public policy through making the most of academic evidence, expertise and experience"* (Oxford, 2021).

Wyborn et al. (2019), have argued that the engagement of scientists should go beyond stakeholder engagement to focus on societal transitions (Wyborn et al., 2019). This is consistent with my understanding as a practitioner, as SPE goes beyond stakeholder engagement or specific models for interfaces. It involves the active engagement of scientists at the science-policy interface to enable evidence-based decisions that delivers favourable outcomes and impacts for climate and society. This can be done through a variety of strategies, including personal interactions, meetings, learning alliances, and platforms (Cramer et al., 2018). SPE is also complementary to, but distinct from, boundary work managing processes around SPIs, and where the boundaries include different disciplines, scales, and forms of knowledge (Clark et al., 2016a). Similarly, boundary spanning, which has been defined by Bednarek et al. (2018) as *"work to enable exchange between the production and use of knowledge to support evidence-informed decision-making in a specific context"*

(Bednarek et al., 2018), is also distinct from science-policy engagement. The main difference is that SPE goes beyond exchange to focus on improved approaches to the production and adoption of knowledge. It has been noted that little is known about the tasks and strategies undertaken at the boundary (Michaels, 2009), which is where SPE fits in.

The term 'engagement' has been defined differently across different contexts, but some common characteristics emerge; these involve using a set of engagement strategies to deliver an agreed upon goal (Resnick, 2001). Based on this interpretation of engagement, for this dissertation I tentatively define Science-Policy Engagement (SPE) as, *'the set of strategies and actions undertaken at the science-policy interface to achieve the goal of informing policy.'* This definition addresses existing calls from scholars; for example, von Schneidemesser et al. (2020) have called for deeper science-policy engagement, i.e., deeper engagement of scientists in the science-policy interface (von Schneidemesser et al., 2020). Engagement has also been identified as a priority for a shared research and action agenda (Sutherland et al., 2012; van Kerkhoff and Lebel, 2006). Furthermore, McNie (2007) highlighted the need to generate practical insights from SPE processes as a priority (McNie, 2007). SPE efforts can be undertaken at different scales – by researchers themselves through research projects, by research managers through research programmes, by research organisations, and at the scale of knowledge and innovation systems.

Scholars allude to the notion of science-policy engagement in earlier work. For example, in the context of global coastal research, it was found that SPE is challenging in its own right (Rudd and Lawton, 2013). It has also been noted that traditional academic and research careers and institutions do not provide incentives or appropriate guidance for engagement (Hetherington and Phillips, 2020; Singh et al., 2019). Examples of SPE as a distinct area of focus are lacking, which this dissertation seeks to address specifically in the domain of climate change, agriculture, and food security in the Global South. In the current context, Cash and Belloy (2020) have illustrated the urgent need to link knowledge to action, as conventional models do not suffice (Cash and Belloy, 2020; Lang et al., 2012). In the context of agriculture and food security, the need for climate related action is urgent. It is therefore imperative to address the need for improved models linking knowledge to action. Scholarly work focusing on the food and agriculture sector has been limited compared to other sectors, excluding the foundational work by Cash (Cash et al., 2003) and Clark (Clark et al. 2016a). Context-specific lesson generation for food and agriculture is therefore a key gap, together with empirical lessons which further theoretical advances. In addition, there have been insufficient studies focused on the Global South (Clark et al., 2016a; Jones et al., 2008). These gaps are especially true in the case of science-policy engagement, which has not been differentiated in the literature, although empirical insights can enable us to do so. In addition to the knowledge gaps there is also an action gap, where the application of SPE lessons that can accelerate the policy changes urgently needed in the sector have been lacking. In order to fill this gap and deliver tangible results for climate and society, approaches to SPE need to be enhanced for better interactions between science and policy.

1.2 Climate change, agriculture and food security

World population is estimated to increase from 7.7 billion in 2019 to almost 10 billion by 2050 (UN, 2019). To feed this growing population, global food production will need to increase by around 56% compared to 2010 levels (Searchinger et al., 2019). However, the accelerating impact of climate change poses a threat to achieving food security and the Intergovernmental Panel on Climate Change (IPCC) estimates that by 2050, climate change will negatively impact the production of major crops (wheat, rice, and maize) in tropical and temperate regions (Porter et al., 2014). The IPCC special report on land found that climate change is already affecting food security, with key systems including crops, livestock, fruits, and vegetables coming under threat (IPCC, 2019). That being said, food systems are also a major driver of anthropogenic climate change. They contribute one-third of global greenhouse gas (GHG) emissions (Crippa et al., 2021). This means that in order to achieve the global goal of curbing temperature increase to less than 2 degrees Celsius, as per the Paris Climate Agreement in 2015 (UN, 2015), emissions from agriculture alone will need to be reduced by ~1 GtCO2e/year by 2030 (Wollenberg et al., 2016). This has led to a growing call amongst the international community for a transformation in food systems (Loboguerrero et al., 2020; Pharo et al., 2019; Steiner et al., 2020), with the UN Secretary-General calling for the first-ever summit to address transforming food systems in the face of climate crisis and biodiversity loss (UN, 2020b).

In the context of climate change, transformation in food systems has been defined as a third change in inputs to the system, e.g. land, labour, capital, or outputs and outcomes of the system such as GHG emissions, resilience of food systems, production etc., within 25 years or less (Vermeulen et al., 2018). To achieve such a transformation, more ambitious policy action is required (Campbell et al., 2016; Howden et al., 2007). For example, the Organisation for Economic Co-operation and Development (OECD) estimates that around USD 720 billion a year is spent on agricultural subsidies in 54 countries, often leading to harmful consequences for the climate (OECD, 2021). Science-policy interactions which address such fundamental distortions in the system are imperative for both people and the planet. The gap between research and implementation (Knight et al., 2008) needs to be bridged, ensuring innovations and ideas emerging from research inform policy and implementation efforts. Science-policy engagement is crucial to accelerate the uptake of innovations and ideas leading to a transformation in food systems, as has been noted in the European context (Turnhout et al., 2020).

Although issues around science-policy interactions are garnering greater attention in the global response to climate change, they have not received due attention within the food and agriculture sector, despite the sector being a major contributor to global greenhouse gas emissions and itself being vulnerable to the consequences of climate change. In the lead up to the first-ever United Nations Food Systems Summit, experts allude to the potential of improved science-policy interactions to catalyse a transformation in food systems (Hainzelin et al., 2021; Roodhof et al., 2021; Turnhout et al., 2021). At the same time, criticisms have been raised as to how such efforts also risk accelerating existing inequities (Clapp et al., 2021).

Constructive science-policy engagement efforts are urgently needed in the sector to respond to the challenges posed by climate change, and to ensure future food security for a growing population. These efforts must focus on delivering outcomes that ultimately realise positive impacts in society (Harding, 2014). This goes beyond enriching or informing decision-making processes, both of which foster positive outputs or outcomes; however, due to the politicised nature of both food systems and climate change, this has proved difficult to achieve. A focus on science-policy engagement at the intersection of climate change, agriculture, and food security will expand the empirical coverage of science-policy studies to these sectors, and embrace the Global South, which remains an important gap in the literature (Clark et al., 2016a). The CGIAR, the international network responsible for agricultural research for development, provides a suitable institutional context to better understand how SPE efforts can be strengthened in operations at different scales. Founded in 1971, the CGIAR has been hailed as the biggest institutional innovation for foreign assistance to agriculture in the 20th century (Byerlee and Lynam, 2020). Climate change is a relatively new area in the CGIAR's work but is increasing in prominence, and the CGIAR Research Program for Climate Change, Agriculture and Food Security (CCAFS) has been the main vehicle for working on climate change issues.

1.3 Science-policy engagement to accelerate a transformation in food systems: main challenges and knowledge gaps

It is imperative to take urgent climate action, not least in the food and agriculture sector, a major contributor of greenhouse gas emissions. However, climate-informed changes in the sector have so far been incremental and there is need for transformative action. Improving science-policy interactions through focused and active engagement has the potential to enable greater action. To achieve this, key knowledge gaps need to be addressed around what works, what doesn't work, and how good practices can be institutionalised and scaled in the sector. These insights can complement further conceptual development of science-policy engagement as a specific area of work within the broader field of science-policy interfaces, enabling more fruitful science-policy interactions. Such efforts can help address recognised challenges to ensuring the salience, credibility, and legitimacy of knowledge generated through active engagement. These need to be unpacked at different scales of action: at the levels of researcher, research programme, research organisation, the knowledge and innovation system and, crucially, across all these scales.

This dissertation addresses two key knowledge gaps: firstly, in the context of science-policy interactions for climate action in the food and agriculture sector, existing approaches to science-policy interfaces have proved insufficient, and I seek to address this gap by expanding the frontiers of SPIs – focusing specifically on science-policy engagement as a distinct area that can enable valuable outcomes and impact for climate and society. Secondly, within the food and agriculture sector, the application of concepts of SPIs has been limited. Empirical studies on SPIs in the Global South are also limited. This dissertation generates empirical lessons from the food and agriculture sector in the Global South, which can be applied to accelerate climate action in the sector across multiple scales and targeting those communities most at risk.

1.4 Research aim, questions and relevance

In this section, I set out the general aim of the dissertation with regards to the key knowledge gaps and problems identified. This is followed by the research questions and the scientific relevance of this dissertation.

1.4.1 Research aim and questions

In the context of the urgent transformation required within the food and agriculture sector to meet climate change and food security goals, advancing research on science-policy engagement as a distinct area within the broader literature on science-policy interfaces and in efforts of practitioners can have both scholarly and practical relevance. This relevance is enhanced by the importance of generating empirical insights at different scales, as the application of such lessons has proven challenging (Cash et al., 2006). All considered, this dissertation aims to generate systematic empirical insights regarding fruitful science-policy engagement within the domain of climate change, agriculture and food security across different scales. This is achieved by studying the efforts of the CGIAR research program on Climate Change, Agriculture and Food Security (CCAFS) as a prominent SPE effort, while remaining embedded within the CGIAR network, the international network for agricultural research for development, and the wider knowledge and innovation system for food and agriculture in the Global South.

CCAFS works on climate change, agriculture, and food security issues in Africa, Asia, and Latin America, with a focus on science-policy engagement (CCAFS, 2013) as a tool to realise development outcomes. Studying CCAFS' efforts at different scales, I first study how research projects within the programme portfolio work to implement SPE successfully. This is followed by an examination of programme-level efforts to operationalise SPE, with a focus on failed efforts and challenges faced by the programme. I then consider CGIAR-wide efforts to tackle climate change and institutionalise SPE, focusing on the organisational-level as a whole and with due regard to CGIAR being the international network responsible for agricultural research for development. To conclude, knowledge and innovation for climate action in agriculture is scrutinised to set out priorities and approaches at the system level. This dissertation thus generates lessons at multiple scales and seeks to lay the foundation for further research and action on SPE. The dissertation's main research question is the following:

> **MRQ**: How can science-policy engagement contribute to more fruitful cross-scale climate action in the food and agriculture sector in the Global South?

This research question emphasises the role of science-policy engagement, where empirical insights are needed as a distinct area of science-policy interfaces. This dissertation develops SPE as a key and distinct part of the literature on SPIs, a contribution which enables further research and action on the topic. Scholars who have identified priorities for the research agenda on SPE call for specifying processes and strategies, formulation of design principles, and an understanding of the role of social, economic, and political external factors (Sutherland et al., 2012; van Enst et al., 2014). These priorities are addressed through this dissertation in that SPE strategies are explored within the context of external factors in the food and agriculture sector, and at multiple scales. Insights are gathered through the application of theories of SPIs (Chapter 2) (Cash et al., 2003), failure management (Chapter 3) (Edmondson, 2011), institutional design (Chapter 4) (Cash et al., 2002), and innovation science (Chapter 5) (Barrett et al., 2020); making the dissertation novel and interdisciplinary. Therefore, this dissertation helps lay the empirical foundations for studies on SPE, broadening the SPI literature through the application of theories from other fields.

That the focus of this dissertation is on food and agriculture, a sector that has been under-studied in relation to science-policy interfaces, further enhances the relevance of its contributions. It also captures my transition from a reflexive practitioner into a scientist; so although this dissertation is brought forth in my capacity as a scientist, I can draw on perspectives obtained as a reflexive practitioner working for CCAFS. This approach, drawing scientific insights from reflexive perspectives, provides cognisance that would otherwise not have been captured in the literature. Such a reflexive approach addresses several key knowledge gaps identified by McNie (2007) on the need for insights on the practical aspects of science-policy relationships, how decisions are made, strategies employed, and challenges faced (McNie, 2007). Such practical issues and challenges are addressed throughout this dissertation.

This dissertation seeks to generate these insights at different scales; indeed, the starting point of my notion of science-policy engagement, as explained in section 1.1, is that the incentives and leverage points for action can be found at the following different scales: by researchers themselves through research projects, by research managers through research programmes, by research organisations, and at the scale of knowledge and innovation systems. Based on efforts to catalyse climate action at different scales within the food and agriculture sector, the following Subsidiary Research Questions (SRQs) study science-policy engagement at different scales of operation:

> **SRQ1**: What are the *success factors* for science-policy engagement for climate action in agriculture?

This question seeks to identify success factors based on good practice examples of SPE at the *project level*, drawing on successful case studies, and will be addressed in Chapter 2.

> **SRQ2:** What are the *fail factors and challenges* for science-policy engagement for climate action in agriculture, and how can these be overcome?

This question seeks to identify fail factors in science-policy engagement – those factors that cause efforts to fail, and challenges that can be faced in the engagement process. From these lessons, an approach to overcome failures and challenges by failing intelligently is also developed. These insights are considered at the *programme level* and are addressed in Chapter 3.

> **SRQ3:** How can effective science-policy engagement be institutionalised in the context of Agricultural Research for Development (AR4D) organisations?

This question seeks to focus on the scale of a *research organisation* and identify lessons to institutionalise effective science-policy engagement, drawing on theories of institutional design. This question is addressed in Chapter 4 of this dissertation.

> **SRQ4:** What are the priorities for transformation in food systems and how can these be actioned in knowledge and innovation systems to enable effective science-policy engagement across the system?

This question focuses on the *knowledge and innovation system* for climate action in food systems and seeks to identify priorities for a transformation as part of a Theory of Change process, thereby enabling fruitful science-policy engagement efforts across the system. This question will be answered in Chapter 5 of this dissertation.

By answering these research questions, this dissertation collects empirical evidence on science-policy engagement at different scales in the context of climate action in the food and agriculture sector (Figure 1.1). These empirical insights, combined at varying scales, bring new insights to the literature on SPIs as a whole and address pressing research priorities around engagement, thereby laying the foundation for further research on SPE as a distinct field within SPIs. These SRQs are answered consecutively, enabling me to build on the lessons learned from one to the other. For example, while preparing Chapter 2, I found that at the project level researchers have challenges, but these were not reported or reflected upon.

Therefore, in Chapter 3 I dive deeper into these failures of effort, where a number of responses from projects led me to focus on the research managers themselves, whose role it is to create the right enabling environment at the programme level.

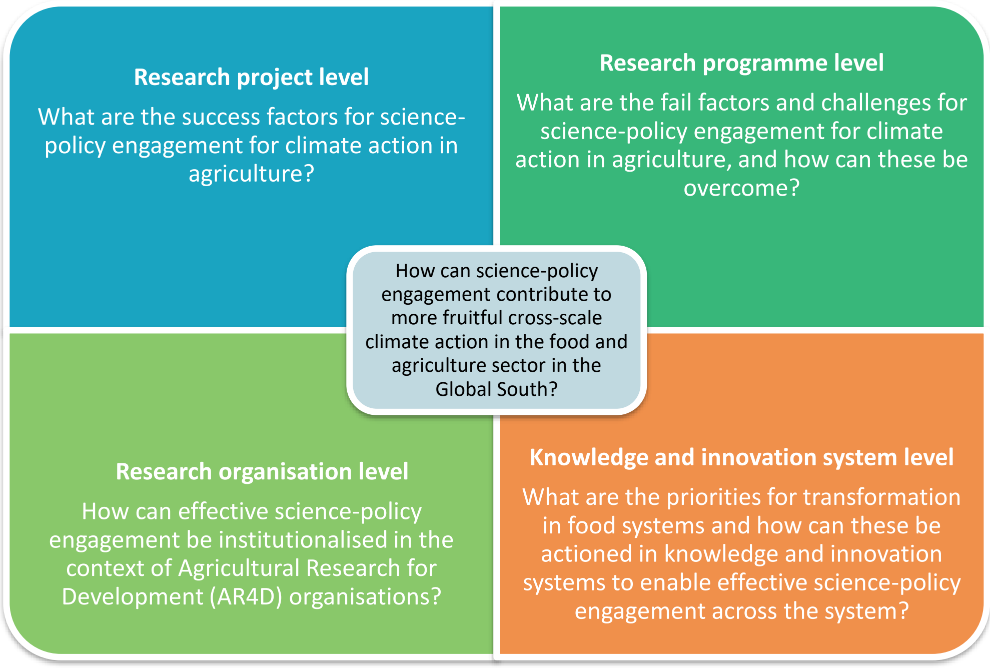


Figure 1.1 Main Research Question (MRQ) and Subsidiary Research Questions (SRQs) of this dissertation

1.4.2 Societal relevance

This dissertation's societal relevance arises from its value to key stakeholders working at the interface between science and policy for climate action in the agriculture and food sector. For researchers working on agricultural research and development, where an estimated USD 56 billion is spent every year (Fuglie et al., 2020), this dissertation offers approaches to improve science-policy engagement efforts and deliver outcomes that benefit society through climate action and food security. Researchers can learn from the success and fail factors identified in this dissertation and thus improve their efforts. For research managers, this dissertation offers additional insight regarding designing effective programmes and organisations to enable future SPE efforts and create a culture that helps deliver positive societal outcomes at scale. The role of science-policy research in supporting decisions organising science itself in the context of climate change has also been noted (Sarewitz and Pielke, 2007), and lessons generated in this dissertation can help organise science to tackle challenges in the domain of climate change, agriculture, and food security. Finally, for investors in agricultural research for development and innovation policy makers, this dissertation sets out the transformative agenda that needs focused efforts to drive changes across the whole knowledge and innovation system.

1.5 Research design, selected case study and methods

The overall research design studies climate change response within the CGIAR at different scales - research projects, programme, organisation, and knowledge and innovation systems, and then applies different methods to arrive at the conclusions. This single embedded case study has been examined at different scales using specific methods and bodies of literature. As noted in 1.4.1, at the project level this dissertation seeks to answer the question, "*What are the success factors for science-policy engagement for climate action in agriculture?"* To answer this question (SRQ1), I focus on successful efforts of science-policy engagement at the project level. This is followed by efforts at the programme level to answer the subsequent question (SRQ2), *"What are the fail factors and challenges for science-policy engagement for climate action in agriculture, and how can these be overcome?"* Here the focus is on failed examples of science-policy engagement efforts and the approach to failures at the programme level. This is followed by an organisation-wide effort to answer the question (SRQ3), *"How can effective science-policy engagement be institutionalised in the context of Agricultural Research for Development (AR4D)?",* a question that focuses on how science-policy engagement efforts were institutionalised in the context of CGIAR's reforms and response to climate change. Finally, the focus shifts to the scale of the knowledge and innovation system for climate action in food and agriculture (SRQ4), *"What are the priorities for transformation in food systems and how can these be actioned in knowledge and innovation systems to enable effective science-policy engagement across the system?",* which draws on perspectives of stakeholders across the system to identify priorities for transforming the system. This can then underpin all efforts to produce knowledge and thereby strengthen the interactions between science and policy for a transformation in food systems.

1.5.1 Case study

This dissertation draws extensively on the case study of the CGIAR, formerly the Consultative Group for International Agricultural Research (CGIAR), the international network responsible for agricultural research for development (Pingali and Kelley, 2007). It has been argued that the CGIAR is the biggest institutional innovation of the 20th century for foreign assistance to agriculture (Byerlee and Lynam, 2020), working to address food insecurity issues to a great extent. While its origins lie in the green revolution, the network has striven to address accelerating climate change systematically since 2009 through the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) (Table 1.1). CCAFS was set up to respond to the mounting challenge of climate change, with a focus on delivering development outcomes and impact through science-policy engagement (Thornton et al., 2017). The approach adopted by CCAFS deviated from the traditional

CGIAR focus on crop breeding and commodities, and took a systemic view combining technologies and practices, climate services and safety nets, policies and institutions, low-emission development pathways, scaling, and gender and social inclusion. CCAFS has spent significant resources in agricultural research for development with a focus on climate change, and in 2019 had a budget of USD 50 million. The case presently studied is thus based on a prominent effort of science-policy engagement in the context of the food and agriculture sector's response to climate change over the past 12 years. During this period, CCAFS' SPE efforts have realised multiple outcomes (Westermann et al., 2018) and impacts (Aryal et al., 2015; Haman and Hertzum, 2019; Hariharan et al., 2020; Murendo and Wollni, 2015; Reddy, 2015). Considering the importance of the food and agriculture sector for climate change mitigation and adaptation, studying the key international network responsible for agricultural research for development through a science-policy engagement lens can help bring valuable insights for scholars and practitioners.

Table 1.1 Climate change through the CGIAR reforms

Year	Description
2007	World Bank Vice President and CGIAR Chair, Katherine Sierra proposes to intensify climate change research in the CGIAR at COP13 of the UNFCCC in Bali (CGIAR, 2007).
2009	CGIAR Challenge Program on Climate Change, Agriculture and Food Security was established, as a new Challenge Program of the CGIAR (CCAFS, 2009), in addition to other thematic programmes which were initiated in 2002 in response to calls for reform in the CGIAR (Douthwaite et al., 2017).
2011	CGIAR Research Programs launched as an alternative to Challenge Programs, including the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) (CCAFS, 2011b; Roy-Macauley et al., 2016).
2014	CGIAR commits to devote 60% of its research to tackle climate change at the UN Climate Action Summit (CGIAR, 2014, 2016).
2017	A new phase of CGIAR Research Programs was announced, with CCAFS as an integrative research programme linking multiple CRPs and centres (CCAFS, 2016).
2019	A new phase of reforms initiated to transition to One CGIAR, with a focus on responding to the climate crisis (CGIAR, 2019).

The value of the focus on the CGIAR case study also comes from the fact that, in comparison to the growing number of studies focusing on other organisations, the CGIAR itself has yet to be systematically studied – this being despite the growing calls for institutional reform in the face of climate change (von Braun and Birner, 2017; Young et al., 2008). This dissertation draws on the work of the CGIAR at different levels: at the scale of research projects, programmes, organisations and finally the knowledge and innovation system itself. Focusing on different scales of operation can inform efforts to reorient the knowledge and innovation system in response to growing calls for a transformation within the sector.

1.5.2 Data collection and methods

A combination of data collection methods are used in this dissertation. In the second chapter, which focuses on the identification of success factors in science-policy interfaces, data was collected through document review and key informant interviews focusing on 34 case studies of successful SPE. The third chapter focuses on fail factors and challenges; here, data was gathered through a project survey and key informant interviews. The fourth chapter relies on external reviews and key informant interviews as sources of data. The fifth chapter is based on a survey with 262 stakeholders in the knowledge and innovation system for climate change, agriculture, and food security.

Table 1. 2 Subsidiary Research Questions and methods applied

Sub Research Question	Methods
What are the success factors for science-policy engagement for climate action in agriculture? (Ch. 2)	• Survey with CCAFS project leaders. • Key informant interviews. • 34 case studies of outcomes delivered through SPE.
What are the fail factors and challenges for science-policy engagement for climate action in agriculture, and how can these be overcome? (Ch. 3)	• Survey with CCAFS projects to secure examples. • Key informant interviews with CCAFS management team members.
How can effective science-policy engagement be institutionalised in the context of Agricultural Research for Development (AR4D) organisations? (Ch. 4)	• Review of literature and external evaluations. • Key informant interviews.
What are the priorities for transformation in food systems and how can these be actioned in knowledge and innovation systems to enable effective science-policy engagement across the system? (Ch. 5)	• Survey with 262 stakeholders in the knowledge and innovation system. • Participant observation at the 5th Global Conference on Climate-Smart Agriculture

1.5.3 Data analysis

As noted in section 1.5.2, different types of data were collected for this dissertation. These range from survey results and interview findings to participant observation and document review; therefore, a variety of analytical tools were used. In Chapter 2, as noted in 1.5.2, the data analysed included survey results, interview transcripts and case studies of science-policy engagement. These were analysed quantitatively using Microsoft Excel and qualitatively using expert judgement. In Chapter 3, data collected included survey results and interview transcripts, and these were also analysed quantitatively and qualitatively. In Chapter 4, I analysed external evaluations of CCAFS through document review and complemented these with the qualitative analysis of interviews with key informants. In Chapter 5, survey results from the 5th Global Science Conference on Climate-Smart Agriculture were analysed quantitively using Microsoft Excel. In addition, I used the participant observation method to generate insights from my role as a key organizer of the conference.

1.5.4 Research ethics and positionality

As an external PhD candidate employed by CCAFS, I have emphasised research ethics as a reflexive practitioner through a critical and academic examination of science-policy engagement efforts within CCAFS in the context of the wider CGIAR network and the knowledge and innovation system. Cunliffe (2016) has defined reflexivity as *"Questioning what we, and others, might be taking for granted—what is being said and not said—and examining the impact this has or might have" (Cunliffe, 2016).* Aligned with this definition, I approached my work within CCAFS, as well as the actions of others, the wider programme, and the organisation, with a reflexive approach – questioning what I would otherwise have taken for granted in my work. This meant reflecting upon my work critically, analysing specific problems encountered and underlying power structures (Mangnus et al., 2021). I consider my reflexive insights as a scientist in this dissertation, strengthening efficacy and avoiding bias.

This approach to SPE practice provides fresh insights into the literature which may not otherwise have been available to an external researcher. The risk of bias was also addressed through co-authorship with scholars unconnected to CCAFS, including the supervisors of this dissertation. In addition, coursework as part of the 'responsible conduct of research' provided theoretical and practical guidance on research ethics including avoiding bias, ethical data collection, and use of data.

1.6 Outline of the dissertation

An outline of this dissertation is shown in Table 1.3. In this first chapter, the focus is on the key concepts around which the dissertation revolves, including the literature, research methods, and societal relevance. The second chapter highlights success factors from science-policy engagement at the level of research projects. The third chapter focuses on the programmatic level and identifies fail factors and challenges involved in SPE. The fourth chapter explores the CGIAR as the international network responsible for AR4D and generates lessons for institutionalising SPE. The fifth chapter focuses on systemic issues for knowledge and innovation systems that can create an enabling environment for SPE. The final chapter provides conclusions, drawing on these lessons across different scales, a key feature of this dissertation. The conclusion also includes the proposed way forward for future research and action.

Table 1.3 Outline of the dissertation

Chapter	**Title**	**Key messages**	**Key domains in the literature**
1	Introduction	• Main and sub-research questions. • Key concepts, literature and methods. • Societal and scientific relevance.	
2	Facilitating Change for Climate-Smart Agriculture through Science-Policy Engagement	• Success factors include engagement (participatory and demand-driven research processes), evidence generation (building scientific credibility while adopting an opportunistic and flexible approach) and outreach (effective communication and capacity building).	• Science-policy interfaces (Cash et al., 2003; Clark et al., 2016a).
3	Learning from failure at the science-policy interface for climate action in agriculture	• Fail factors include lack of credibility, salience and legitimacy; institutional arrangements and capacity; power dynamics; and funding uncertainties. • Failing intelligently through planning for failure, minimizing risks, effective design, making failures visible, and learning from failures.	• Science-policy interfaces. • Failure management (Cannon and Edmondson, 2005; Edmondson, 2011).
4	A Changing Climate for Knowledge Generation in Agriculture: Lessons to Institutionalise Science-Policy Engagement	• Lessons to institutionalise effective science-policy engagement including, increased accountability; use of boundary objects; participation across the boundary; mediation and a selectively permeable boundary; translation; coordination and complementary expertise; effective leadership; and presence of incentives.	• Science-policy interfaces. • Institutional analysis and design (Cash et al., 2002; Ostrom, 2011).
5	Enacting theories of change for food systems transformation under climate change	• Adopting a Theory of Change which consists of empowering farmer and consumer organisations, women and youth; digitally-enabled climate-informed services; climate-resilient and low-emission practices and technologies; innovative finance to leverage public and private sector investments; reshaping supply chains, food retail, marketing	• Innovation science (Barrett et al., 2020; Pigford et al., 2018). • Systems transformation (Campbell et al., 2018; Loboguerrero et al., 2020)

		and procurement; fostering enabling policies and institutions; Knowledge transfer; addressing fragmentation in knowledge and innovation systems; and ensuring food security.
6	Conclusions	• Lessons from across scales and next steps. • Implications for SPI from SPE across scales and an interdisciplinary approach to improve science-policy interactions.

CHAPTER 2

FACILITATING CHANGE FOR CLIMATE-SMART AGRICULTURE THROUGH SCIENCE-POLICY ENGAGEMENT

This chapter is published as:

Dinesh, D.; Zougmore, R.B.; Vervoort, J.; Totin, E.; Thornton, P.K.; Solomon, D.; Shirsath, P.B.; Pede, V.O.; Lopez Noriega, I.; Läderach, P.; Körner, J.; Hegger, D.; Girvetz, E.H.; Friis, A.E.; Driessen, P.P.J.; Campbell, B.M. Facilitating Change for Climate-Smart Agriculture through Science-Policy Engagement. Sustainability 2018, 10, 2616. https://doi.org/10.3390/su10082616

2.1 Introduction

The agricultural sector is at the intersection of three major challenges. Firstly, all aspects of food security (availability, access, utilisation and price stability) are affected by climate change (Porter et al., 2014) and adaptation efforts are needed to achieve food security and secure rural livelihoods. Secondly, even as the increasing (largely negative) climate impacts are being felt across crop, livestock and fisheries systems (Porter et al., 2014), agricultural systems needs to produce 60% more food by 2050 compared to levels in 2005/07 (Alexandratos and Bruinsma, 2012). The sector, which is a major employer and pathway out of poverty (FAO, 2015), will need to sustain an increasing number of smallholder farms, expected to rise to about 750 million by 2030 (Campbell and Thornton, 2014). Thirdly, agriculture (and the broader food system) is in itself a major driver of climate change, contributing globally 19–29% of anthropogenic greenhouse gas (GHG) emissions (Vermeulen et al., 2012c). In order to achieve the global goal of limiting temperature rise to 2 degrees Celsius, which was adopted as part of the Paris Climate Agreement in 2015 (UN, 2015), the sector will need to reduce emissions to the extent of ~1 $GtCO_2e$/year by 2030 (Wollenberg et al., 2016), as current technologies and practices can only deliver 21% to 40% of needed mitigation (Wollenberg et al., 2016). In addition to climate change, agriculture is also a major driver for exceeding planetary boundaries for biosphere integrity, biogeochemical flows, land system change and freshwater use (Campbell et al., 2017). The concept of climate-smart agriculture (CSA) responds to these triple challenges, by sustainably increasing productivity and enhancing achievement of food security goals, enhancing resilience, and reducing greenhouse gas emissions where possible (Lipper et al., 2014). These outcomes are addressed in a context specific manner as their relevance will vary in different contexts (Lipper et al., 2014). Given the far-reaching changes which are needed within the sector, more ambitious policy options are required (Howden et al., 2007; Wollenberg et al., 2016). The gap between research and implementation (Knight et al., 2008; Sayer and Cassman, 2013) will need to be bridged, and agricultural research for development (AR4D) will need to transform to enable achievement of development outcomes (Thornton et al., 2017) in a rapid and effective manner, where innovations emerging from research inform policies and implementation efforts. In this context, the CGIAR (formerly the Consultative Group on International Agricultural Research), the world's largest and most experienced research network for AR4D (Clark et al., 2016a; McCalla, 2017; Ozgediz, 2012) has a major role to play to ensure that its approach to AR4D responds to the challenges and opportunities posed by climate change. The climate change programme of the CGIAR, the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), was developed to respond to these challenges and opportunities in a concerted manner (Ozgediz, 2012), and invested USD 414 million from 2011-16 on AR4D in relation to CSA. CCAFS adopted a theory of change approach to achieve development outcomes (Thornton et al., 2017) and science-policy engagement efforts are at the heart of this approach (Vermeulen et al., 2012a). In this paper, we evaluated the CCAFS programme theory on science-policy engagement in relation to actual case studies of science-policy engagement leading to development outcomes, and based on the results, we propose a revised improved programme theory to enhance credibility, salience and legitimacy (Cash et al., 2003). This offers empirical insights to researchers and practitioners of science-policy engagement, and a pragmatic approach for AR4D research efforts to be more outcome-oriented in the context of climate change. Our findings also have practical implications, with CCAFS initiating a second phase, involving a proposed research investment of USD 388 million from 2017-22 (CCAFS, 2016), to enable the programme to effectively achieve its goals of helping 11 million farm households adopt CSA, assisting 9 million people out of poverty, improving the food and nutritional security of 5.5 million people, and reducing agriculture-related greenhouse gas emissions by 0.16 Gt CO2-e/year (CCAFS, 2016).

The interface between science and policy has emerged as an important aspect of research efforts in the context of global environmental change (Cash et al., 2003; Clayton and Culshaw, 2009; Hering et al., 2014; Kates et al., 2001; Lang et al., 2012; McNie, 2007; UNEP, 2017), and can offer valuable insights to improve science-policy engagement in the context of CSA. Science-policy engagement enriches decision making through exchanges, co-evolution and joint construction of knowledge by interactions between researchers and policy actors (Van den Hove, 2007). Enriching decision-making involves the use of scientific knowledge in policy processes to understand the problem setting, to explore, design and implement policy responses, to inform policy evaluations, and to apply knowledge systematically in dialogue between different stakeholders (van Enst, 2018). Several studies have identified "best" practices for science-policy engagement, including clear and strategic communications, targeting, ensuring accessibility to research findings, timing, developing a policy acumen, participation in policy processes, knowledge brokering, and joint knowledge production (Edelenbos et al., 2011; Marshall et al., 2017; Rose et al., 2016; Sitko et al., 2017; Stringer and Dougill, 2013). However, operationalising the best practices identified and generating outcomes is not simple (Gluckman, 2016), various challenges have been identified including trade-offs in terms of time and resources, maintaining quality, oversimplification, maintaining continuity of engagement efforts, institutional and organisational challenges, and achieving coherence between demand and supply of knowledge (Neßhöver et al., 2013; Sarkki et al., 2014; Talwar et al., 2011; Van Enst et al., 2014). In relation to climate change, the fragmented nature of scientific knowledge on its causes, mechanisms, effects, response strategies and time horizons involved (Leroy et al., 2010) and the shift in governance, from a state centric approach to an approach which also focuses on non-state actors (Lemos and Agrawal, 2006; Meadowcroft, 2007), make science-policy engagement complex. Notable among studies on science-policy engagement is Cash et al. (2003), who set the overarching aim of science-policy engagement efforts as to maximise credibility, salience and legitimacy (Cash et al., 2003). Credibility refers to the perceived adequacy of the knowledge produced and salience to its perceived relevance. Legitimacy refers to the extent to which knowledge production has been respectful of the divergent values and beliefs of stakeholders, unbiased in its conduct and fair in its treatment of opposing views and interests (Cash et al., 2003; Hegger et al., 2012).

In this context, further areas for research on science-policy engagement emerge. Van Enst et al. (2014), have identified priorities for a research agenda in science-policy interface, which includes the identification of design principles for engagement efforts in specific contexts (Van Enst et al., 2014). Sutherland et al. (2012), have also proposed elements of a research agenda for science-policy research, which includes understanding the role of scientific evidence in policy-making (Sutherland et al., 2012). These priorities match those identified at the convergence of climate change, agriculture and food security. Steenwerth et al. (2014) have identified research on institutional and policy aspects, specifically the role of science-policy partnerships and science-based actions to be a key theme for research in this area (Steenwerth et al., 2014). However, systematic empirical assessments, to gain insights into mechanisms of co-evolution of policy-demand and scientific capability to realize development outcomes (Nelson et al., 2010) are limited, and we aim to contribute to addressing this gap by offering a sectoral perspective from AR4D in relation to CSA.

We address the question: in the context of achieving climate change and food security goals, what are the success factors for science-policy engagement in AR4D in relation to CSA, to inform policies and realise development outcomes? The empirical insights which we present will be from developing country contexts, where such empirical insights into science-policy interfaces are limited (Clark et al., 2016a). We examined the programme theory of the CCAFS, a key player in science-policy interface related to CSA, which invested USD 414 million from 2011-16 on AR4D in relation to CSA, we then evaluated how the programme theory has performed using case studies, inspired by literature on programme theory evaluation and reconstruction (Hoogerwerf, 1990; Leeuw, 2003; Rogers, 2008), to propose a revised and improved programme theory. The CCAFS programme theory is in line with what many believe to be good practices for science-policy engagement efforts and is consistent with the literature (Abson et al., 2017; Bielak et al., 2008; Cash et al., 2003; Clark et al., 2016a; Fullana i Palmer et al., 2011; Proust et al., 2012; Thornton et al., 2017). Therefore, any insights into how the programme theory works in practice, and revisions which are needed, will not only enable better design of science-policy engagement efforts, but also make an important contribution to the literature on science-policy engagement, where much of the focus has been on conceptual insights, and systematic empirical insights into what works in practice are only emerging.

2.2 Contextualisation of programme theory

In response to the climate change challenges faced by the agricultural sector, CCAFS adopted a theory of change approach which is grounded in the achievement of development outcomes through the provision of incentives, greater flexibility, encouraging learning and improving effectiveness of its researchers (Thornton et al., 2017). As part of the programme's approach to facilitating policy change, the programme leadership, Vermeulen and Campbell (2015), drew on the literature and the programme's experiences to put forward a programme theory (Vermeulen and Campbell, 2015) consisting of ten principles. As is highlighted in scholarly literature on the evaluation of programme theories, a programme theory is not a scientific theory but instead a depiction of the logic used by the programme management. By evaluating this programme theory, the plausibility, soundness and feasibility of the theory can be assessed, and the results can improve science-policy engagement efforts and contribute to the emerging empirical literature on science-policy engagement. Although these principles were formulated in the context of the CCAFS programme, they are consistent with present day insights into conditions for successful science-policy interactions, as the added linkages to the wider literature including path breaking papers may signal (Table 2.1). The principles provide researchers part of the programme with a pragmatic approach to realise development outcomes, and emphasise on the production of demand driven research, effective engagement in policy processes, building scientific credibility, strategic communications and capacity building. In addition, the principles take cognisance of the political nature of policy processes and call for tackling power and influence, navigating towards leverage points, and for mainstreaming higher level goals such as food security and poverty alleviation in science-policy engagement efforts. The principles also call for a different approach to resource allocation, investing a third of resources for engagement and communications respectively. Lesson learning is also considered to be important, and co-learning with policy makers and internal learning by researchers, are also highlighted.

Table 2.1 Principles underlying the CCAFS programme theory explained

1. Navigate towards specific points of leverage	Points of leverage are areas where a small intervention can lead to large changes (Proust et al., 2012). Weak leverage points have limited ability to drive change (Abson et al., 2017), therefore it is essential to identify leverage points which are tangible and have the ability to drive change. In the context of complexity associated with confronting wicked problems such as climate change, this principle proposes that science-policy engagement efforts should navigate towards points of leverage, which are likely to lead to change (Vermeulen and Campbell, 2015).
2. Allocate resources in three thirds	This principle proposes that effective AR4D programmes should invest a third of resources on research, a third on engaging with next users and a third on improving the capacity of next users for uptake of research (Vermeulen and Campbell, 2015). This principle is derived from lessons learnt from life cycle assessment studies (Fullana i Palmer et al., 2011). This does not mean strict allocation of financial resources in thirds, but adopting an approach which puts

	emphasis on partnerships and capacity building, in addition to generating sound science (Thornton et al., 2017).
3. Join in external processes	This principle proposes that rather than creating new processes and events, science-policy engagement efforts should join existing processes of next users wherever possible (Vermeulen and Campbell, 2015). This includes boundary spanning work (Kristjanson et al., 2009) between researchers and user groups, to define products and to foster dialogue.
4. Use research products to build scientific credibility	Enhancing credibility, i.e. scientific adequacy of technical information, is key to successful science-policy engagement (Cash et al., 2003). Cash et al. (2003) found that in addition to credibility, salience and legitimacy are important factors, in order to respond to the needs of next users, and to ensure that the process is fair and respectful of stakeholders (Cash et al., 2003). This principle proposes that researchers should use a strategy based on high impact publications, research and open access policies, to enhance their scientific credibility and thus support science-policy engagement processes (Cash et al., 2003).
5. Sustain co-learning throughout policy engagement and implementation	Co-learning processes facilitate knowledge exchange, co-production and learning in the science-policy engagement process (Abson et al., 2017; Proust et al., 2012). This principle proposes that through co-learning processes research products should be tailored and translated to suit needs of next users.
6. Tackle power and influence	Power relations, including the status of individuals involved in the engagement process may affect the outcomes of the process (Fazey et al., 2012; Hegger et al., 2012). This is especially true in the case of the agricultural sector, where knowledge is highly politicised (Cash et al., 2003) and researchers need to navigate power relations. Also, in the context of power and influence, the United Nations Environment Programme has called for gender equality in all science-policy activities, to avoid aggravating existing inequalities (UNEP, 2017). This principle proposes that researchers should be mindful of gender and other power differences (Vermeulen and Campbell, 2015).
7. Invest in and monitor capacity enhancement	Strengthening the capacity of farmers and agricultural sector actors such as extension services is a priority to enable farming communities to cope with climate change impacts (Lipper et al., 2014). Capacity enhancement efforts can both help next users better articulate demand, and to effectively translate knowledge into actions at the field level (Clark et al., 2016a). In this context, AR4D has a role to play, and the principle proposes that research efforts should focus on enhancing the capacity of next users and research partners and measuring progress (Vermeulen and Campbell, 2015).
8. Mainstream higher-level goals	AR4D efforts integrate research activities and outputs with an impact pathway leading to development outcomes, and international development partners pursue this pathway to realise impacts for higher level goals such as improved livelihoods and food security (Thornton et al., 2017). This principle proposes mainstreaming higher-level goals of poverty reduction, gender equity, social inclusion, environmental sustainability and improved nutrition in policy engagement efforts, to help focus on development outcomes (Vermeulen and Campbell, 2015).

9. Create mechanisms for internal learning	Mechanisms for internal learning, such as a theory of change approach, can help balance research efforts with the priorities of next users (Thornton et al., 2017). This principle proposes that researchers should include processes to review the theory of change, re-align the strategy for impact, and seize emerging opportunities in order to be successful (Vermeulen and Campbell, 2015).
10. Communicate strategically and actively	Effective communication between researchers and next users is a key boundary management function (Cash et al., 2003), and the emphasis of communication efforts has shifted from generic approaches to targeted ones which facilitate knowledge brokering (Bielak et al., 2008). This principle proposes that research efforts should develop communications strategies to link closely with the impact pathways identified.

2.3 Methods

Over the period 2011-16, CCAFS, completed its first six-year phase, which involved a cumulative research investment of USD 414 million. In this period, the programme worked in over 20 countries, at the local, sub-national and national levels, and complemented in-country actions with efforts at the regional and global levels. The focus of the programme was on context-specific actions, thus consistent with the interpretation of CSA (Lipper et al., 2014). Over this period, 210 case studies of science-policy engagement leading to outcomes were reported as part of programme wide reporting. Outcomes are changes in behaviour, relationships, activities, or actions of non-research partners with whom a programme works (Earl et al., 2001), while outcomes are important milestones in the pathway to impact, they are not measures of actual impact which are further downstream and long term in nature (Harding, 2014; WKKF, 2004). CCAFS interprets outcomes as use of research by non-research partners to develop new, or change, policies and practices. The outcome case studies reported were evaluated by the programme's management unit and independent experts representing user groups (farmers and development practitioners), and the latter experts' scores were accorded higher weight (66%) to avoid any form of bias from internal reviewers. The case studies were evaluated across three criteria: significance, evidence availability and clarity. Significance, the criterion accorded the highest weight focused on how significant or transformative the impacts arising from the outcome are likely to be and how widely these are likely to be felt (Scoble et al., 2010). Evidence availability was the criterion accorded the second highest weight and focused on how good the evidence was for a research-attributed outcome (Penfield et al., 2014). The third criterion was clarity, which focused on how clearly the narrative (Penfield et al., 2014) describes the outcome and associated activities, using qualitative and quantitative information. Based on the scoring across these three criteria, 41 case studies were rated highly. In addition to the information submitted as part of programme-wide reporting, we endeavoured to collect additional qualitative and quantitative data relating to these 41 case studies, through semi-structured interviews and a survey (Fowler Jr, 2013) structured around the programme theory, together with open ended questions to bring additional insights that may not fall under the proposed principles (e.g. what were the three most important success factors which helped achieve this outcome?). We received responses in relation to 34 case studies and these form the basis of this paper (Appendix 1). CCAFS is a reflexive programme, and the authors of this paper include the Programme Director, Global Policy Engagement Manager, researchers, and science-policy interface experts from outside the programme, which ensures unique insights of reflexive practitioners as well as external insights from science-policy interface experts outside the programme.

The case studies (Kingsley, 1993; Penfield et al., 2014) are narratives of science-policy engagement efforts undertaken by researchers part of the programme, and outline the activities conducted, related research outputs, partners, next users and evidence to attribute the outcome to research efforts. The case studies include engagement with national and sub-national governments, regional and international processes, development banks, investors and non-governmental organisations, who are next users of the research as opposed to the final beneficiaries (e.g. smallholder farmers and rural communities) who benefit from the impact generated by the research. The semi-structured interviews and survey (Fowler Jr, 2013) was conducted with 23 researchers who led science-policy engagement efforts in the case studies. The programme theory which formed the basis for the interviews and survey, revolves around ten principles for effective AR4D programmes, identified by the programme based on its experiences and from the literature, which is consistent with the different terms for programme theories identified by Hoogerwerf (1990) (Hoogerwerf, 1990).

Semi-structured interviews provided insights into processes of science-policy engagement adopted in the case studies, while the survey responses included ranking of the importance of the proposed principles on a five-point scale (5 = very important, 4 = important, 3 = fairly important, 2 = slightly important, 1 = not important), and provide quantitative data for statistical analysis. We analysed the data to identify patterns of similarities across survey results and correlation amongst the proposed principles. In addition, we also endeavoured to understand the challenges and failures faced by researchers, through an open-ended question on challenges and failures encountered in the engagement process. The results were used to critically assess the programme theory (Leeuw, 2003). Although the responses are self-reported opinions of the respondents, and this may be considered a limitation, in order to reconcile the supply and demand for knowledge (Sarewitz and Pielke, 2007), it is important to understand supply side perspectives and experiences to design research and engagement efforts which can deliver outcomes more effectively.

2.4 Results

Results from the interviews are examined below in relation to the 10 principles outlined within the programme theory (Vermeulen and Campbell, 2015). This helps to ascertain the relevance of the principles and the context. This is followed by summaries of explanatory factors, challenges observed, and quantitative analysis based on the survey.

2.4.1 Navigate towards specific points of leverage

Due to the complexity involved in engaging at the intersection of climate change, agriculture and food security, navigating towards leverage points in science-policy engagement efforts was found to be an effective approach by many of the respondents. For example, researchers at the International Institute of Tropical Agriculture (IITA) engaged in East African policy processes to scale up climate-smart banana coffee intercropping systems discovered that *"The higher up you go in terms of the innovation the more you have to understand complexity and the more important it becomes to understand your leverage points. When you come with superb genetic material, sooner or later people will discover it and take it up and the more you go up in that scale, from plant, to plot, to farm, to community, to landscape to national level, the more the complexity and the leverage points become more important"* (Case 4). Even in cases where this principle was not explicitly highlighted as an important factor, the role of leverage points in science-policy engagement efforts came out implicitly, as illustrated by this quote, *"we tried to listen as much as possible to our next users to understand what they were really needing according to their specific characteristics and basically responding to their demands. Even though this topic is very complex we tried to focus on what was really the need of our next users and that helped us a lot to focus on our research agenda"* (Case 31). The need to navigate complexity comes out quite strongly in most cases, although in some contexts this is less relevant, for example when research efforts are directed by a policy process, as illustrated in Case 1, *"addressing complexity was not that important as this was directed research, we focused on water resources, agriculture and food security as leverage points as that is the focus of the International Water Management Institute".* Leverage points identified in the case studies included navigating towards higher level goals like food security, engaging through multi-stakeholder processes, and linkages with present day issues and concerns of policy makers. These varied depending on the scale of efforts, for example while at the community level, the leverage point could be nutrition of the community, at the global level, it could be global food security. Leverage points also appeared to differ based on the stage within the policy cycle, for example whether at the decision or implementation stage of the policy process.

2.4.2 Allocate resources in three thirds

In majority of the case studies, the respondents found an approach to research which integrates communications and engagement desirable as these help build relationships with users. For example, while engaging with the African Group of Negotiators on agriculture and climate change issues, it was important to allocate resources for research, engagement and communications, as recognised by one of the respondents, *"all the three issues identified were fairly critical. This happened at the time when we were building relationships with our partners, at the time CCAFS had just started. So it was very important to invest in different avenues so we were able to establish a working relationship with the different partners." (*Case 5). In a number of cases, the principle did not seem to be integrated at the planning phase. However, when analysing how things happened and how resources were allocated, respondents realised that the distribution of resources had reflected this principle, as illustrated by this quote, *"we did not explicitly follow this principle, but our basic approach (find out what next users' needs and priorities are), research in relation to these priorities, and communicate with users to move towards uptake, was in effect what we did"* (Case 28). While the overall approach of investing in research, engagement and communications resonated with most of the respondents, the need to adapt this to the context of each research project was highlighted by many respondents, for example, in some contexts research projects are designed solely with the aim of putting research into use as explained by one respondent, *"In this case, the research had been done beforehand, and we were not doing a research activity. Resources allocated were: 50% to relationship building, 0% to research and 50% to improve the capacity to enhance uptake of science."* (Case 16). On the other hand, some respondents recognised that even if they considered the three components equally important, more resources were generally allocated to research. Others explained that at the beginning of their project, research was considered more important, and only after learning and adapting the other two components, the resources were expended at the same level.

2.4.3 Join in external processes

Taking cognisance of the fact that engaging in existing processes can be more efficient than "re-inventing the wheel", majority of the respondents were in agreement with this principle, as one respondent (Case 10) noted, *"it is important to join them on processes dealing with current issues, which are already in place…"* (Case 10). Building on existing processes allows to embed new interventions in the larger institutional fabric in order to capture more benefits. For example, in the case of informing policies and investments through participatory future scenarios, the respondent noted, *"we are basically inserting ourselves into policy processes and that is the whole project"* (Case 8). However, in instances where an existing process may not be present, it becomes essential to create a new process, but it is important to engage the relevant stakeholders in these new processes to ensure sufficient buy-in, as illustrated by this quote, *"these were new things that were happening, so it is not that there was a process that was going on, so again with them, we started a new way of using climate information to make decisions on the ground"* (Case 31).

2.4.4 Use research products to build scientific credibility

While the role of scientific credibility in science-policy engagement was reaffirmed by most of the respondents, as argued by case 10 - *"We really need to strengthen science and build credibility. The credibility comes from past research, and takes some time to build, it relates to both the credibility of the individual as a scientist and also that of the institution",* the case studies show that in addition to credibility of research products, the credibility of research institutes, researchers themselves, and processes were important factors. The inclusiveness and participation of next users in research processes also played a role in research uptake. In case studies where this principle was not found important, we found that this was due to context-specific factors, for example where the expectations of stakeholders were not scientific outputs but business models, as illustrated in this quote, *"stakeholders were most interested in business models that suit their working context. This is not an area where scientific credibility matters, but our past experience in developing successful business models served the same purpose - establishing credibility"* (Case 28).

2.4.5 Sustain co-learning throughout policy engagement and implementation

Co-learning in policy engagement and implementation appeared to be more relevant in cases where participatory processes with next users were involved, for example, participatory scenario development or co-development of products, here co-learning becomes an important strategy to put research into use, as illustrated by this quote, *"If you work in isolation and then come up with some output and then share the output with the next user, it is very difficult to convince them. But if you keep the stakeholders or the next users in the loop from the beginning it is really helpful to communicate your work with them"* (Case 24). In these cases, respondents felt that achieving policy influence requires more than a linear approach because policy processes are complex, influenced by a number of divergent and sometimes competing claims and factors. Therefore, respondents recommended setting aside time for trust building among the stakeholders involved to lay the ground for consensus building and to create a window of opportunity for policy change. However, in cases where decision making processes are closed and occur in short time frames, there are fewer opportunities for co-learning, as illustrated by one of the respondents, *"over the short term there is not really this two-way interaction between the information going out on the television and people trying it out in the field"* (Case 21).

2.4.6 Tackle power and influence

Tackling power and influence was a key aspect of many of the case studies, as shown in the Colombia case (19) - "*Our strategy was first to learn who were the powerful players".* Having tacit knowledge about the different stakeholders, including influence, motivation and limitations of the key actors as well as information and financial flows within the organisations was an important factor to tackle power differences. Strategies for tackling power and influence were many, including stakeholder mapping, working with champions in target institutions, and combining bottom-up and top-down approaches. Identifying leverage points and using tailored approaches for the different stakeholders was also highlighted as good practices. As a respondent noted, *"Power was very important. There are umpteen numbers of players in the insurance industry, therefore a stakeholder mapping was used to identify the key persons that we need to link with. This was why Maharashtra was selected, as they were Government and industry officials who could make a difference"* (Case 29). At the community level, empowerment, capacity building of farmers, and communities to deal with local power imbalances was an effective way observed in two case studies.

While gender considerations were not observed in majority of the case studies, others recognised addressing gender inequalities to be very important while tackling power and influence, as one respondent explained, *"as we worked on the process we realised that addressing gender issues in the dairy value chain would be essential, not only in achieving the overall effectiveness but also equitable outcomes as well, so we undertook some extra work together with private sector companies to understand how they can incorporate gender issues into their marketing and service delivery activities"* (Case 28).

2.4.7 Invest in, and monitor, capacity enhancement

Investing in capacity enhancement was found to be important in majority of the cases: *"It (capacity enhancement) is very important. (...) There's no point in talking about a particular practice if you don't follow up when people need particular information. I think enhancing capacity was a key point in this"* (Case 21). Case studies included activities to strengthen the capacity of research partners as well as those of next users, although capacity enhancement of next users was considered more important than of research partners. For next users, focus of capacity enhancement was rather directed to interpreting scientific information, while efforts to enhance capacities to conduct research were undertaken with research partners. Government organisations, non-governmental organisations (NGOs), national research institutions, farmer organisations, and private sector actors were the key beneficiaries of capacity enhancement efforts. Some case studies highlighted that capacity enhancement is not necessarily an essential component of all research for development strategies, for example when part of an international process such as the Intergovernmental Panel on Climate Change, and in another instance, there was reverse capacity enhancement efforts, with researchers' capacity being enhanced as a result of engaging with next users. In all cases, capacity enhancement efforts were monitored through the planning and reporting system used by CCAFS.

2.4.8 Mainstream higher-level goals

This principle did not resonate with many of the respondents, especially when these goals were perceived to be too broad and unhelpful in achieving outcomes, for example in the case of scaling up index-based insurance in India, the respondent noted that, *"The next users are more interested in day-to-day work and insurance related terms. They wanted to improve the scheme, which may implicitly take into account these goals"* (Case 29). However, in the cases were this principle was found relevant, the three major high level goals commonly seen were: ensuring food security, poverty reduction, and environmental sustainability. Multi-agency collaboration, alignment with government and donor priorities were among the key factors revealed by the respondents as motivations in setting high level goals.

2.4.9 Create mechanisms for internal learning

While in the majority of cases, internal learning processes helped in realigning strategic approaches and improving implementation tactics, researchers also benefitted from these processes to respond to emerging opportunities. For example, in the case of scaling out climate-smart villages in Haryana, India, the respondent noted, *"When we work in the diversity of partnerships, diversity of people, diversity of geographies, all those things, then we see what is important where. The same approach may not be appropriate for achieving those outcomes, so I think targeting the stakeholders is important for that outcome"* (Case 24). While not many case studies had explicit Theories of Change (ToC), many of the case studies had implicit ToCs, which were perceived to be more flexible and allowed researchers to be opportunistic, and save time spent in writing detailed ToCs.

2.4.10 Communicate strategically and actively

There appeared to be broad agreement on the importance of strategic communications efforts. In the only case where communications was found to be unimportant, the focus was on informing governments and international organisations in policy or investment decisions, and therefore closed processes. The approach to communications varied across case studies even when they agreed on the importance of communications, few case studies had a formal communications strategy, while others responded to demand, but agreed that if they had had a communications plan, impact would have been higher. While a formal communications strategy was absent in many cases, components of a communications strategy such as videos, mass media, social media, blogs, direct communications etc., were included by most of the case studies. Often, communications with stakeholders was done through events or other forms of direct communications. Many also used print and non-print formal and social media outlets to communicate results and increase impact. Internal communications, understood as communicating with stakeholders at all levels, e.g. farmers, government representatives, etc. is often crucial for success, and will, despite a lack of a communications strategy, often be part of the project. External communications is more varied but is seen as important for scaling up and generating wider uptake.

2.4.11 Explanatory factors for successful science-policy engagement

In addition to questions related to the ten principles discussed earlier on in this section, we also asked respondents for their views on what they considered as the most important factors in their science-policy engagement efforts. This helped identify additional explanatory factors for success as well as getting further nuances on the principles. We found that, engagement of key stakeholders (including research partners and next users) was a common success factor. Designing research efforts such that they address the priorities of next users was another common success factor, together with an opportunistic and flexible approach to respond to changes in demands. Opportunism refers to the ability of projects to identify emerging needs and to engage in local, national or international processes that will facilitate the uptake of the research products or add value to them. Flexibility to readapt the project objectives in order to deliver solutions for meeting the identified needs and align the project to relevant processes was recognised as critical for the success of the projects. Scientific credibility, including the credibility of scientists themselves as well as the credibility of their organisations was another important success factor. Strategic communications to share research findings was identified by some of the cases as important, and the need for a wide range of communication tools targeting different audiences was recognised by most of the case studies.

2.4.12 Challenges in science-policy engagement efforts

We endeavoured to understand the challenges and failures which researchers face while engaging at the science-policy interface. Replicability of successes was often seen as a challenge, wherein the success in one region/context cannot be replicated within another region/context, differences in policy priorities were mentioned as one of the main reasons for lack of replicability. Lack of follow up is another challenge, which leads to efforts not realising full potential in terms of results. Another challenge that emerged was the lack of ex-post impact assessments which mean that full sense of how partners use science is often unavailable. Some of the respondents mentioned how efforts may have failed due to external factors beyond their control, such as rapid turnover of local, national and regional government staff, policy priorities etc. In addition to challenges, some of the projects referred to ‘serendipity’ as a key factor which enabled them in their efforts, i.e. being at the right place at the right time.

2.4.13 Quantitative analysis and contextualisation of principles

Across the 10 principles which we assessed (Vermeulen and Campbell, 2015), building scientific credibility and strategic communication of research results stood out as having the highest importance on average (average of 4.5 on the 1-5 scale). Mainstreaming higher level goals was ranked as having the lowest importance on average (average 3.3), with 32% of case studies reporting this as having little to no importance (score of 1 or 2). However, we found differences in the rankings across scales (Figure 2.1), for example at the local and national scale, the principle of understanding power differences was rated as significantly more important than in the case studies at the global scale ($p < 0.001$ and $p < 0.01$; Tukey’s Honest Significant Difference). Similarly, there were also scale differences as to how other principles were rated. For example, case studies at the global and local scale rated scientific credibility as significantly more important than those at the national/regional scales. Some of the principles were correlated—particularly navigating complexity and understanding power differences ($r = 0.48$), and co-learning and capacity building ($r = 0.45$)—showing these principles are explaining much of the same variance.

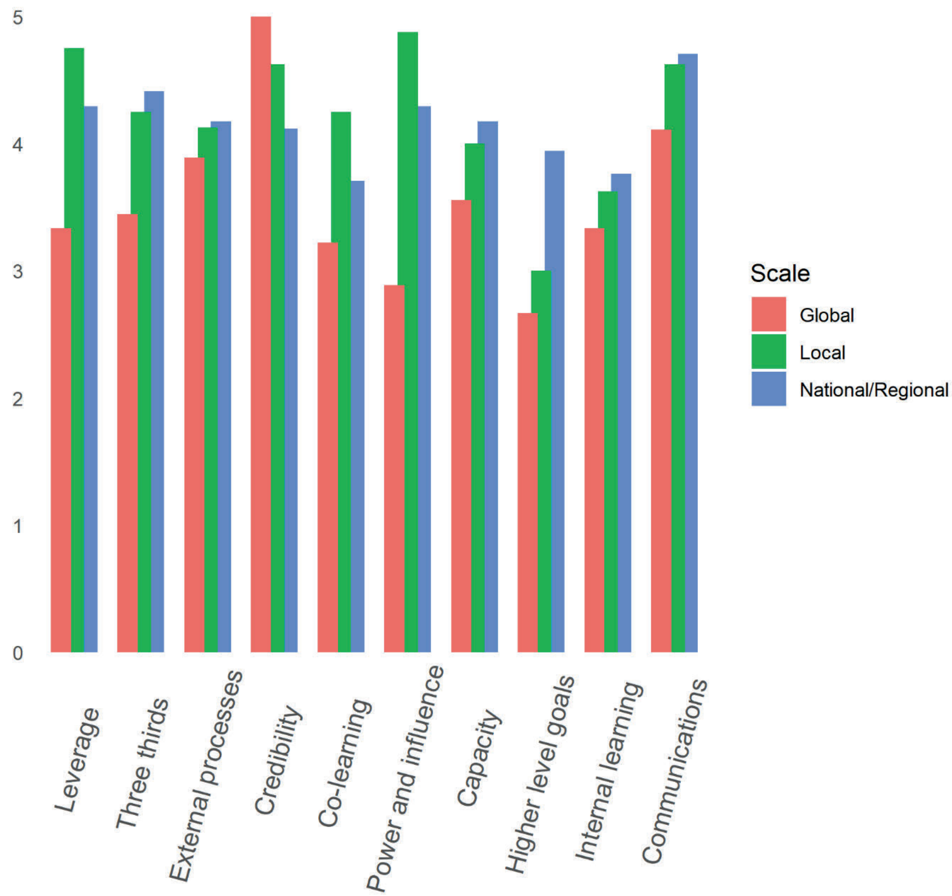


Figure 2.1 Average score of each principle by different scales of case studies

The analysis of the case studies reveals that on average 11% of the case studies find one or more principle either slightly important or not important, indicating different behaviours have played roles in facilitating outcomes. Among all the principles "Communications" appears to be the most consistently important across all the outcomes. The principles mainstreaming higher level goals (32%), sustained co-learning (21%) and internal learning (21%) are the ones with highest percentage of projects ranking them as slightly or not important. Consequently, there is no strict rule on applicability and importance of these principles highlighting the contextualisation of them depending on the nature of the case study, type of the stakeholders and most importantly, how efforts are operationalised in achieving successful outcomes.

2.5 Discussion

We used the 10 principles for effective AR4D proposed by Vermeulen and Campbell (2015), the programme theory of the CCAFS programme, as the basis for our analysis, while rooting these principles in relevant existing literature. In general there is overlap between the principles, which became evident in the case studies. For instance, while the fifth principle proposes sustaining co-learning, this is also reflected in capacity enhancement efforts (principle 7). Similarly, while principle 10 proposes a strategic communications approach, communications activities are taking place in relation to many of the other principles. A demand-driven research approach will incorporate multiple principles including those relating to co-learning (principle 5), internal learning (principle 9) and capacity enhancement (principle 7). Consequently, there is no strict boundary between these principles, and what is important is how these are operationalised in the context of each case study. However, upon empirically scrutinising the principles, their relevance for enhancing credibility, salience and legitimacy (Cash et al., 2003) in AR4D was confirmed, and the results offer an opportunity to nuance the principles, synthesise some of them and to specify how they work in the context of enhancing credibility, salience and legitimacy. In order to do this, the principle which calls for allocation of resources in thirds (principle 2) provides a useful framing, as it calls for redistribution of research effort into three broad areas: 1) *engagement* with partners and stakeholders; 2) developing *evidence*; and 3) *outreach* through communication and capacity building. The three thirds principle draws on lessons in life cycle analysis (Fullana i Palmer et al., 2011), and offers an approach to operationalise the concepts of credibility, salience and legitimacy identified by Cash (2003) for AR4D under climate change, drawing upon empirical insights from the case studies analysed. (Cash et al., 2003). Table 2.2 compares the three components of knowledge systems for sustainable development (Cash et al., 2003) against the three thirds principle, which identifies opportunities for actions to improve science-policy engagement.

Table 2.2 Comparison of the three thirds principle against the key components of knowledge systems for sustainable development (Cash et al., 2003)

	Credibility	**Salience**	**Legitimacy**
Evidence	- Generation of scientifically adequate technical evidence and arguments. - Building credibility of researchers through high quality publications. - Building credibility through complementary methods (knowledge products, participation in processes etc.).	- Flexible and opportunistic approach to ensure results are tailored to the needs of next users.	- Unbiased and rigorous research outputs.

Outreach	- Communicating research results actively to build credibility among decision makers.	- Enhancing capacity of decision makers for uptake of research results. - Communicating research in formats that can be understood and used by decision makers.	- Two way communications to incorporate diverse views.
Engagement	- Building credibility of researchers through active participation in scientific and policy processes.	- Demand driven research which address the knowledge needs of decision makers	- Participatory approaches to enhance legitimacy by taking into account divergent values and beliefs.

To enrich this framing with empirical insights drawn from this study, we elaborate the three areas further as explained below.

2.5.1 Engagement

While allocating a third of research effort to engagement efforts, two key components emerge for effective operationalisation, notably: (i) participatory approach and (ii) targeted and demand driven approach.

(i) Participatory approach

Participatory approaches were observed in a number of case studies, e.g., through interaction with government officials and researchers, through joint scenarios development processes, co-production of knowledge products etc. Coproduction of knowledge with next users has been identified as an effective strategy for science-policy engagement (Cash et al., 2003), and Hegger et al., (2012) has proposed a set of success conditions for joint knowledge production including the creation of a protected space for knowledge development and allocation of appropriate resources (Hegger and Dieperink, 2014; Hegger et al., 2012). The case studies show that relying on participatory approaches can enable researchers to effectively engage with next users for open dialogue, mutual learning, and consensus decisions. However, effective science-policy engagement strategies rely on developing an understanding of the expectations and interests of the stakeholders, and protected spaces for joint knowledge production and appropriate resources to support such spaces should be a priority. Coproduction of knowledge can also stimulate ownership, and make room for tension to emerge (e.g., certain issues discussed can be controversial or provocative, there may be unexpected dynamics or competition between participants).

(ii) Targeted and demand driven approach

Reconciling the supply for knowledge to meet the demand emerging from stakeholders is key (Sarewitz and Pielke, 2007). In order to operationalise this, the case studies showed a targeted and demand driven approach by researchers to be crucial. Almost all the case studies have taken a demand driven approach, which helps ensure that knowledge produced is salient to next users. The trend towards demand-driven research has focused attention on the inclusion of users (e.g., farmers, policy makers) in research planning. Theoretically, this should enhance ownership and increase the applicability of research. However, in practice, several tensions emerge with regard to the operationalisation of such 'user-driven research planning systems' (e.g., information asymmetries between the actor groups which can influence their capacity to successfully act in the research planning system etc.). A demand driven approach can help ensure that research is salient (i.e., relevant to the needs of next users) (Cash et al., 2003).

2.5.2 Evidence

Effective science-policy outcomes are underpinned by credible evidence, and key components for generating credible evidence include (i) scientific credibility, and (ii) opportunism and flexibility.

(i) Scientific credibility

As observed in the results, a vast majority of the respondents found this to be an important factor in science-policy engagement efforts, and this was highlighted in detail in several case studies. Scientific credibility enabled researchers to get involved in processes led by private sector and Government agencies, and thus inform their decisions. In order for scientific information to be accepted by end-users (e.g., policy-makers), it must be credible, and it is important for researchers to think about how accurate and credible the information being produced is, in order to be useful. While Cash (2003) interprets credibility as the adequacy of the technical evidence and arguments (Cash et al., 2003), we found that beyond the technical evidence and arguments, the credibility of the individuals and institutions also play an important role, i.e., in addition to the credibility of knowledge produced, the credibility of knowledge producers and knowledge producing institutions are also important factors in science-policy engagement. As Heink et al. (2015) points out, it is necessary to specify the concept of credibility for specific contexts (Heink et al., 2015), and we find that this needs to be broadened to cover the credibility of institutions and individuals.

(ii) Opportunism and flexibility

Researchers require the flexibility to pursue opportunities as part of their science-policy engagement efforts. Many of the case studies' success depended on responding to opportunities as and when they appeared, for example by responding to an opportunity rather than as part of a planned impact pathway. Therefore, a key aspect of science-policy engagement efforts is to maintain flexibility and to be opportunistic, which enable the production of knowledge salient to user needs. Dealing with policy partners involves different timeframes to research project timelines and researchers need to be flexible to these (Kothari et al., 2009). Therefore, it is essential for researchers to seize opportunities when they arise. Participatory approaches can be useful for researchers to engage with next users and adopt approaches which adapt to their needs (Stringer et al., 2006). In the context of reconciling the supply of and demand for science, Sarewitz and Pielke (2007) have highlighted the concept of missed opportunities, wherein opportunities to connect science with policy are missed when research agendas may not meet next user demands or when social or institutional constraints prevent information use (Sarewitz and Pielke, 2007), and a flexible and opportunistic approach can be a solution in some of these contexts as observed from the case studies.

2.5.3 Outreach

Reaching out to next users, including through strategic communications as well as through capacity building efforts is the third area to focus on, and it includes (i) communications and (ii) capacity building.

(i) Communications

A majority of the case studies noted communications to be of importance in science-policy engagement efforts, and communications activities included formal as well as informal approaches. This takes cognisance of the growing transition of traditional science communications to knowledge brokering characterised by targeted approaches to inform different stakeholder groups (Bielak et al., 2008). Communication between researchers and policy makers is not easy, and difficulties associated have been highlighted by various authors (e.g. Guston 2001, McNie 2007, Holmes and Clark 2008) (Guston, 2001; Holmes and Clark, 2008; McNie, 2007). Cash (2003) has also noted the importance of active, iterative and inclusive communications with decision makers (Cash et al., 2003). Researchers and research managers need to take cognisance of the importance of communications and incorporate it as part of their research strategy. Effective communications underpins most of the case studies which we analysed. Communicating (complex) research findings to non-scientists is challenging, but necessary, because next users need to understand, accept, and use the research outcomes/findings. Despite the importance of communicating effectively with next users, we have to be aware that communication is not simply a one-way transmission of information from the scientist/research to intended audience; but rather, it is an iterative, engaged process in which both the science and the stakeholders benefit from exchanges of information.

(ii) Capacity building

In AR4D, capacity building is crucial to articulate the demands of next users and to convey scientific findings to non-specialists (Clark et al., 2016a; Leeuwis et al., 2018). In the case studies which we examined, this role of capacity building was evident. This crucial role of capacity building is taken for granted in other sectors (Clark et al., 2016a), but in the rural development context, it is an area which needs explicit focus. The case studies show that capacity building should be part of the overall outreach efforts, complemented with the communications strategy for results. Capacity building efforts can also enable active engagement of stakeholders and provide greater legitimacy for knowledge generated.

2.6 A revised and improved programme theory

Based on the framing provided by the three thirds principle, and the components identified within the three focal areas, we propose a revised and improved programme theory, which can be applied by the CCAFS programme and more broadly for AR4D under climate change. This programme theory for effective science-policy engagement is captured in Figure 2.2 and proposes allocating research effort in thirds. The first one-third of research effort should focus on engaging early and throughout with key partners and stakeholders within the impact pathway. Researchers need to join in key processes, actively participate and ultimately identify ways to navigate the stakeholder networks and institutional dynamics. These engagements should help make the research demand driven and ideally the research products are co-designed with next users. The second one-third of effort should go toward developing scientifically credible evidence. The research to develop evidence should allow for opportunism and flexibility to take advantage of quickly emerging needs along the impact pathway. This has traditionally been where the bulk of research efforts have focused, but it needs to be balanced with engagement and outreach efforts. The final one-third of the research effort should go toward outreach. This includes communicating research outcomes in formats that can be understood and used by the next users, and capacity building to enable use of research outputs and to ensure sustainability of the outcomes generated.

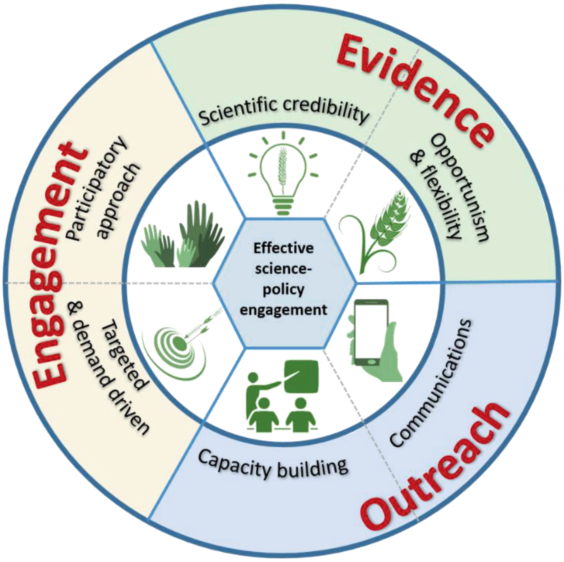


Figure 2.2 Programme theory for effective science-policy engagement

Encountering challenges and difficulties is bound to happen in every research project, and the importance of learning from these challenges is crucial for success. However, we have not included a separate component for lessons learned, as it should be part of any monitoring, evaluation and learning process. From the analysis, it was clear that most researchers are aware of how important planning is, but many also referred to the element of serendipity in reaching outcomes. The element of serendipity cannot be planned or measured but will be an intrinsic element of success. Social, cultural and historical contexts also affect the success of science-policy engagement efforts, and it is not possible to have a uniform approach across contexts, and science-policy engagement should be tailored to the context.

2.7 Conclusion

In many areas of research, there is a major gap between science and action, or, more narrowly, between science and policy; in health, public policy, conservation and agriculture – a phenomenon long recognised but entrenched (e.g. (Haines et al., 2004; Knight et al., 2008; McNie, 2007; Nilsen et al., 2013). In the context of sustainable development, enhancing credibility, legitimacy and salience through science-policy engagement has been identified as a priority to overcome this gap (Cash et al., 2003). To meet this priority and generate tangible outcomes, within the agriculture sector, we found that an approach which relies on engaging stakeholders to demand and co-develop knowledge (i.e., engagement), generation of scientifically credible evidence in an opportunistic and flexible manner to be salient (i.e., evidence), and communicated in appropriate formats together with capacity building efforts to raise capacity for implementation (i.e., outreach) can accelerate progress towards global goals for climate action and food security. However, while such an approach may offer a promising new way to achieve development outcomes, the large-scale adoption of such an approach will depend on the existence of incentives for researchers. Current systems for measuring scientific quality limits researchers' engagement in processes that generate societal impact (De Silva and K. Vance, 2017). New ways of measuring scientific performance, including measuring actual societal outcomes, as practiced by the programme from which this data set has been drawn could help make a shift. Such a shift is inevitable if we are to overcome mega-challenges of achieving food security, adapting to climate change and mitigating emissions from agriculture. Data from such outcomes can also be used to learn lessons, as lessons learning is crucial, as we attempt to improve in the face of these mega challenges.

CHAPTER 3

LEARNING FROM FAILURE AT THE SCIENCE-POLICY INTERFACE FOR CLIMATE ACTION IN AGRICULTURE

This chapter is published as:

Dinesh, D., Hegger, D., Vervoort, J., Campbell, B.M, Driessen, P.P.J., 2021. Learning from failure at the science–policy interface for climate action in agriculture. *Mitigation and Adaptation Strategies for Global Change*, *26*(1), pp.1-24. https://doi.org/10.1007/s11027-021-09940-x

3.1 Introduction

Agriculture and its related activities contribute 23% of global anthropogenic greenhouse gas emissions (IPCC, 2019), and significant emissions reductions are needed from the sector to meet the target of limiting global warming to 2 degrees Celsius as set out in the Paris Climate Agreement (Wollenberg et al., 2016). Efforts to enhance ambition in the lead up to the 26th Conference of Parties (COP) of the United Nations Framework Convention on Climate Change (UNFCCC) to keep warming well below 2 degrees, and to strive towards 1.5 degrees, would require even greater ambition within the sector. At the same time, the sector is the source of livelihoods for those dependent on the over 475 million small farms (Lowder et al., 2014). These small-scale farmers are among the most vulnerable to the impacts of climate change and actions are needed to enable them to cope with climate change impacts (Loboguerrero et al., 2018). Actions to mitigate and adapt to the impacts of climate change need to occur as the world has seen an increase in hunger since 2014 (FAO, 2018). In this context, the Agricultural Research for Development (AR4D) community needs to step up efforts to innovate in the face of climate change, and to inform decision making to ensure large scale uptake of innovations (Dinesh et al., 2018; Steiner et al., 2020; Vermeulen et al., 2012b). Science-policy engagement has become a crucial tool for researchers working on agriculture and climate change, to inform decision making and enhance the impact of their work (Dinesh et al., 2018; UNEP, 2017).

Research on science-policy engagement in the context of environmental change has identified ways to improve the efficacy of these efforts (Cash et al., 2003; Clark et al., 2016a; Holmes and Clark, 2008; Kristjanson et al., 2009). Much of the lessons are drawn from successful case studies and empirical studies are still emerging (Dunn and Laing, 2017; Van Enst et al., 2014). So far, lessons have not been generated systematically from failures (Turnhout et al., 2020; Wyborn et al., 2019), which can be a powerful tool to facilitate innovation, and as Thomas Watson said, *"the way to succeed is to double your failure rate"* (von Stamm, 2018). Lesson learning from failure has been found to drive innovation in various contexts (Danner and Coopersmith, 2015; Heath, 2009; Knott and Posen, 2005; von Stamm, 2018), including in telecommunications (Baumard and Starbuck, 2005), information technology (Gupta et al., 2019), policy making (Dunlop, 2017), pharmaceuticals (Khanna et al., 2016), microfinance (Woolcock, 1999) etc. Despite these advances, our understanding of failures and lesson learning from failures remains quite limited (McGrath, 2011), and this is especially true in the case of science-policy engagement for climate action in agriculture. There is an opportunity to address this knowledge gap, while at the same time applying lessons generated to improve the efficacy of science-policy engagement efforts and thus accelerate climate action.

Science-policy engagement scholars have identified challenges involved in the engagement process (e.g. (Laing and Wallis, 2016; Neßhöver et al., 2013; Sarkki et al., 2014; Talwar et al., 2011; van Enst et al., 2014). However, much of these insights emerge from studying successful case studies, and while successes are recorded and reported, failures often remain undetected or are neglected (McGrath, 2011; Rajkotia, 2018; Vinck, 2017). At the same time, studies in science-policy engagement show that current approaches to informing policy processes are not always delivering sufficient results (Hoppe et al., 2013; Kirchhoff et al., 2013; Strydom et al., 2010; van Kerkhoff and Lebel, 2006), and there is a need to shift to fundamentally different approaches. Scholars have noted that failures in science-policy engagement are inevitable (Armitage et al., 2015; Lawton, 2007; Wyborn et al., 2019), yet an effort to systematically generate lessons and learn from these failures has not been undertaken. In this context, this paper aims to generate lessons from unsuccessful science-policy engagement efforts and challenges of the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

CCAFS is an international research programme with a focus on outcome-oriented research (Thornton et al., 2017; Vermeulen et al., 2012a), working with over 700 partner organisations at the local, sub-national, national, regional and global levels to improve the livelihoods of small-scale farmers in the face of climate change. Outcome delivery is a key criterion to measure performance of projects. CCAFS interprets outcomes as changes in policies and practices of non-research partners (Dinesh et al., 2018; Earl et al., 2001), this includes informing policies and practices of Governments, international organisations, private sector, non-governmental and farmer organisations. Examples include informing national policy and associated investments in Cambodia through participatory scenarios, and provision of climate services to farmers in Senegal (Westermann et al., 2018). The programme's performance in delivering such outcomes is monitored through annual reporting processes. CCAFS' emphasis on outcome delivery and science-policy engagement as a tool to achieve outcomes makes it a good case to study in the context of the emerging literature on Science-Policy Interface Organisations (SPIORGs) (Sarkki et al., 2019), within the wider literature on boundary organisations (Guston, 2001).

CCAFS management is open to learning from its experiences, and past studies have generated lessons from the programme's science-policy engagement efforts (Cramer et al., 2018; Dinesh et al., 2018; Zougmoré et al., 2019), but, also within CCAFS, lessons from unsuccessful efforts and challenges are yet to be studied systematically. Studying failure within organisations is difficult because of psychological and organisational barriers (Cannon and Edmondson, 2001). However, as a research program with a mandate for 'lesson learning', CCAFS is open to learning from its failures. In this chapter, we have endeavoured to combine insider perspectives from two of the authors associated with the programme with outsider perspectives from the other co-authors. The research questions we answer in the context of facilitating change for climate action in agriculture through science-policy engagement, are: what challenges and failures can be faced? What strategies can be adopted to overcome these challenges and failures? To answer these questions, we first developed an explanatory framework based on the literature, consisting of factors which could potentially explain failure in science-policy engagement efforts. We then used this framework as the basis to administer a survey to CCAFS' project leaders and coordinators. The results from this survey were analysed to identify challenges and failures in the CCAFS context, and an approach has been developed to 'fail intelligently'. Thereafter, we also conducted interviews with CCAFS management to validate our findings. Thus, in addition to contributing to the literature on science-policy engagement, failure management and AR4D, this chapter will also help researchers to develop more effective science-policy engagement strategies which are more resilient to challenges and failures.

3.2 Explanatory framework

We understand unsuccessful science-policy engagement efforts or failures as instances where the expected outcome from efforts are not achieved, i.e. where goals are unmet (Kunert, 2018; Leoncini, 2017). In the context of CCAFS this means efforts to drive changes in policies and practices of non-research partners are unsuccessful. Failures arise as a result of challenges or 'fail factors' which may be faced in the science-policy engagement process, and we consider these challenges or 'fail factors' to be independent variables, with 'failure of science-policy engagement efforts to achieve expected results' as the dependent variable. While several challenges may be experienced in policy-engagement processes, 'fail factors' are differentiated by the direct link that these have to the dependent variable. From the perspective of execution of science-policy engagement efforts, existence of these 'fail factors' may be considered to be 'early warning signs' (Leoncini, 2017) that the expected outcome may not be achieved. The explanatory framework (Table 3.1) is envisaged as a context-specific tool to analyse failures (Edmondson, 2011), with the proposed fail factors hypothesised based on the literature on science-policy engagement. Three of the hypothesised fail factors are a reversal of success factors identified by Cash et al (2003), wherein principles of credibility, salience and legitimacy, are considered key success factors in science-policy engagement. We in turn make the assumption that lack of these success factors could lead efforts to fail. We complemented the Cash principles with additional factors including role of intermediaries, power dynamics and institutional capacity, as these feature prominently in the literature on science-policy engagement efforts.

Table 3.1 Explanatory framework for failures in science-policy engagement efforts

Dependent variable	Independent variables (Hypothetical fail factors)	Literature sources
Failure of science-policy engagement efforts to achieve expected outcomes	Decision makers do not perceive knowledge generated to be credible. This perception may be influenced by the research outputs, institutions and researchers themselves.	(Cash et al., 2003; Sarkki et al., 2014; Spilsbury and Nasi, 2006)
	Knowledge generated is not salient to the needs and expectations of decision makers, thereby preventing uptake.	(Cash et al., 2003; Janse, 2008; Sarkki et al., 2014)
	Knowledge generated is not considered to be legitimate, i.e., fair and balanced, which in turn affects uptake.	(Bromley-Trujillo and Karch; Cash et al., 2003; Sarkki et al., 2014)
	Non-existence of suitable intermediaries and knowledge brokers, which affect the iterative nature of engagement processes.	(Clark et al., 2016a; Dilling and Lemos, 2011; Guston, 2001)
	Adverse power dynamics, influenced by ongoing policy discourses and narratives, types of actors involved and their motivations, and policy spaces.	(Cáceres et al., 2016; Keeley and Scoones, 2014; Lawton, 2007; Strydom et al., 2010; Wolmer et al., 2006; Young et al., 2014)
	Lack of institutions willing to absorb and retain knowledge, or a lack of capacity within such institutions, which are deterrent to stability of ideas put forward.	(Armitage et al., 2015; Carlsson and Jacobsson, 1997; Radaelli, 1995; Sarkki et al., 2019; Turnheim et al., 2020; Woolthuis et al., 2005)

3.3 Methods

Learning from failures within organisations is difficult and even learning organisations struggle due to the challenges involved (Cannon and Edmondson, 2005). These challenges include technical ones, due to a lack of understanding of processes to learn from failure, as well as social challenges which stem from psychological reactions to failure. In this context, learning from failure, although important, is a challenging endeavour. To overcome technical challenges faced in learning from failure, we drew on the literature on failure management. To address social challenges around learning from failure, we tried to create a safe and open environment for researchers to share challenges and failures that they have faced. This was done in several ways, firstly, while two of the authors are associated with CCAFS, the other authors are external to the programme, and ensure greater objectivity. The survey was sent out by the second author who is an academic and not directly involved in CCAFS, which could help ensure that respondents were not at risk of bias or evaluation by the programme's management. Findings from the survey were processed anonymously and are presented at an aggregate level. From the responses, it is not possible to deduce the identity of individual respondents, neither is it possible to relate the responses to the performance of individuals. Despite this, there was substantial non-response – this might signal that talking/writing about failure is a delicate matter within CCAFS, as in other contexts.

In order to understand failures faced in CCAFS science-policy engagement efforts, we conducted a literature review and developed an explanatory framework (Table 3.1). We then used the explanatory framework to design a survey (Appendix 2) which was administered to Leaders and Coordinators of CCAFS projects. The objective of this survey was to validate explanatory factors identified, gain further insights on how these factors affect science-policy engagement efforts, and to identify additional explanatory factors. CCAFS had a portfolio of 54 ongoing research projects at the time of this study, and the survey was sent to the Leaders and Coordinators of all these projects as it was not possible to identify projects with explicit failures, since failures are not formally reported. Therefore, we took an open-ended approach, reaching out to all Project Leaders and Coordinators. In addition to the current portfolio, we also contacted Project Leaders and Coordinators of completed projects, to ensure that prior experiences are also captured. The survey was sent to a total of 156 recipients and we received 24 complete responses, which form the basis of our analysis. While the response rate is fairly low compared to the average survey response rate of 52.7% with a standard deviation of 20.4 in organisational research, (Baruch and Holtom, 2008), this shows the difficulty associated with studying failure. 13 recipients of the survey attempted to answer it did not complete it. This may have been due to uncertainty about issues related to failure (as explained by one respondent) or concern in disclosing these experiences. While we recognize the limitation of the sample to be statistically significant, the insights gained are useful for interpretative qualitative research which captures experiences from the CCAFS context. To address challenges associated with studying failure, the responses were anonymised, enabling respondents to frankly share their challenges and unsuccessful science-policy engagement experiences. The results were analysed thematically (Guest et al., 2011), and common themes were identified using an inductive approach, and are presented in the results section. Thereafter, the Leaders of CCAFS' four flagship research programmes (priorities and policies for CSA, climate-smart technologies and practices, low emissions development, and climate services and safety nets), and the program's Director and Head of Global Policy Research were interviewed using a semi-structured approach (See Appendix 3) to share further insights. Based on these insights, we further refined the explanatory factors consisting of challenges in science-policy engagement efforts, and generated lessons to fail intelligently and to improve efficacy of efforts. It must be noted that the survey respondents and interviewees do not represent research users, while it is important to capture the perspectives of users, in this study we endeavoured to get greater granularity about the issues faced by researchers and gain perspectives on knowledge production.

3.4 Results

3.4.1 Knowledge generated is not perceived as credible

42% of the respondents associated their challenges to the first type of factors listed in Table 3.1: demonstrating credibility to partners. In the case of these respondents, the issues varied, ranging from time constraints to build credibility to complexity and uncertainty involved in research outputs, which undermine efforts to build credibility. Lack of quantitative data to support engagement efforts and capacity to conduct analysis required by decision makers were also factors which affected efforts to build credibility (Table 3.2).

Table 3.2 Inductive categorisation of challenges encountered in demonstrating credibility

Complexity	**Complexity of research outputs made it difficult to repackage in format that was user friendly and scientifically credible.**
Quantitative data	Lack of quantitative data including economic data, sex disaggregated data, adoption rates, impact, etc., which are needed to demonstrate credibility to decision makers was lacking.
Uncertainty	Uncertainty in research results as well as conflicting results from other sources made it difficult to demonstrate credibility.
Case studies	Lack of case studies of solutions already working in other developing countries or in other regions within the focal country.
Capacity	Limited or no capacity to conduct sound multidisciplinary analysis to address demand from decision makers and to show systemic linkages and interactions.
Time constraints	Decision makers are time constrained, which makes it difficult to improve communications and build credibility.

3.4.2 Knowledge generated is not salient

A majority of the respondents (63%) associated their challenges with research goals, questions and results not being salient to the needs of decision makers, the second category of explanatory factors from Table 3.1. Respondents encountered a number of challenges (Table 3.3), including lack of sufficient conversations and dialogue with decision makers, differences in timelines of research and decision making, retaining decision makers' attention, misunderstandings with decision makers and non-technical factors needed to inform decisions. Science-policy engagement can often be a long process and ensuring that the salience is retained across this process, even when there are changes to other factors, is important. A respondent noted, *"Main challenge here is with respect to continuous changes of government staff. When the project starts, the goals are aligned but once people move or leaders change, those goals, all of a sudden, become not very well aligned"*. This points to the need for adaptive strategies to ensure and retain salience in the engagement process. Such strategies included the setting up of science-policy multi-stakeholder platforms, getting results validated by decision makers, applying methods which are quicker, being flexible to changes in the decision-making process, and developing a coherent theory of change and network mapping.

Table 3.3 Inductive categorisation of challenges encountered in achieving salience

Insufficient engagement	Further conversations and dialogue, and efforts to communicate are needed.
Differences in timeframes	The time horizon of research and decision making is different. Decision making in policy can be rather fast, while research processes can be slower.
Retaining the attention of decision-makers	It might take many years of persistent engagement to ensure change and retaining attention to an issue over a long time can be challenging considering conflicting priorities and turnover.
Misalignment between demand and supply of knowledge	The demand for research results may differ from what researchers believe is the demand. For example, when pursuing environmental targets, policymakers do not necessarily want to hear about social equity outcomes.
Retaining alignment over time	Often when a project starts, the goals are aligned but once key decision makers or their support staff change roles, those goals are no longer well aligned.
Making the case for engagement	Researchers often need to make the case for decision makers to engage on a topic, before actually presenting options for policy. For example, there is often the perception that gender is not a relevant issue. As a result, it is necessary to compile and present existing and relevant sex-disaggregated data and knowledge, first to make the case that gender applies in the sector/area and secondly to present credible models and options for policy.

3.4.3 Knowledge generated is not legitimate

Only 22%[1] of the respondents found their challenges to be related to decision makers not finding the research to be legitimate, the third explanatory factor from our framework (Table 3.1). In these instances where decision makers found issues relating to legitimacy, this was due to the complexity of research, theoretical rather than practical orientation, lack of sufficient information (including other views), conflicts of interest, and existing prejudices, for example on gender roles.

In the climate change context, communicating uncertainty can be a factor which informs the perceived legitimacy of knowledge, and respondents undertook a number of efforts to communicate uncertainty effectively. These included participatory processes to engage stakeholders and make them aware of uncertainties, convening roundtables with decision

[1] We only received 23 responses to this question, as opposed to 24 responses to other questions.

makers, developing multiple scenarios, and tailored approaches to supporting decision making. Overall, a fair and balanced approach where researchers are upfront about the limitations and uncertainties associated with their research was the dominant strategy, and existence of different communication channels was crucial.

3.4.4 Engagement process lacked appropriate intermediaries

Lack of appropriate intermediaries was not found to be a problem, as a majority of the respondents (73%) relied on intermediaries including knowledge brokers and boundary organisations in their engagement efforts. These included Non-Governmental Organisations (NGOs), United Nations (UN) agencies, private sector consultancies, national research institutes, and government agencies (Table 3.4). In addition to institutions, the role of thought leaders and champions was crucial in several instances. These are individuals well connected and respected in decision making processes and are able to connect researchers to decision making processes. Referring to one such thought leader, a respondent said, *"He seems to have links to everyone. He invited CCAFS to participate in a working group that was going to consolidate efforts on adaptation tracking tools"*. Of the respondents that did not use intermediaries, only two indicated that using intermediaries could have been valuable.

Table 3.4 Types of intermediaries engaged and their roles

NGOs to work closely with farmers in delivering science and effective implementation of policies.
Sub-national organisations for engagement and implementation at the sub-national level.
UN organisations including the Food and Agriculture Organisation (FAO) and the World Bank in global engagement activities.
National research institutes and government departments to engage decision makers at the national level.
Thought leaders and champions at different scales, providing the opportunities to engage in different processes.
Consultancies who draw up governmental plans and proposals, with a mandate to integrate research findings.
Regional bodies and networks, for example Central American Agricultural Council and the African Group of Negotiators Expert Support (AGNES), for provision of inputs into regional strategies and policy documents.
Private sector bodies, convened their partners or facilitated speaking opportunities at stakeholder events.

3.4.5 Adverse power dynamics

Adverse power dynamics were a key factor affecting science-policy engagement process observed by 70% of the respondents, and the role of researchers within these dynamics influence the success or failure of efforts. There were differences in how respondents viewed the role of researchers in such power dynamics. While some of the respondents believed that researchers should remain distant and neutral to these, others believed that researchers should actively engage in these, as one respondent remarked, *"when power dynamics are in play, you* *play within them. Scientists and science are not outside of political action, we're in the middle of it, if not necessarily central to it".* Power dynamics are often not within the control of researchers and in some instances, the science community is not considered to be a political heavy weight, and such factors are also taken into account when developing strategies to navigate these. Many approaches were taken to navigate power dynamics encountered, including remaining neutral and evidence-based, providing *quid pro quo* support to help advance goals, engaging in political processes, and identifying champions who can help navigate the power dynamics. Overall, researchers need to be extremely cautious while engaging in such power dynamics, engaging proactively but respectfully.

Table 3.5 Inductive categorisation of challenges in navigating adverse power dynamics in science-policy engagement

Remaining neutral and evidence based and ensuring that all voices are heard by engaging groups with different perspectives.
Quid pro quo needed to ensure that research results are taken up.
Lack of an understanding of the importance of power dynamics, especially the key demands, what is at stake and ensuring that the final solution is scientifically proven and robust while meeting the demands of interested parties.
Engaging in political processes and highlighting issues that policymakers may prefer to ignore.
Identifying champions within the partner organisations who can help navigate these power dynamics.
Difficulty in engaging powerful players - they may require careful discussion and convincing.

3.4.6 Lack of institutional capacity

Most of the respondents (78%) found that their impact partners had adequate capacity to absorb research findings. Where capacity gaps existed, these related to sufficient technical staff not being available, capacity gaps to achieve scale with initiatives, and a lack of understanding of technology requirements and funding models for effective implementation.

3.4.7 Inductively derived fail factors in science-policy engagement

In addition to exploring the hypothetical fail factors of our explanatory framework, we posed an open ended question on the top three reasons why science-policy engagement efforts failed to achieve expected outcomes, and respondents came up with a number of different reasons which we list as empirical fail factors (Table 3.6). Where these fail factors add further contextual detail to the hypothetical fail factors in our explanatory framework (Table 3.1), we have indicated this, while other factors outside the explanatory framework are also listed. Our assumption that lack of salience is a key fail factor is validated, but the survey results show the nuance involved. While in some cases this is because of research results not addressing the needs of decision makers, in other cases this is due to a lack of demand for science-based solutions among decision makers. Similarly, while we hypothesised institutional capacity gaps among partners to be a fail factor, we find that these gaps also extend to CCAFS researchers and manifest in the form of limited capacity for engagement and communications and to form and maintain partnerships. Differences in organisational cultures is also a key manifestation, which emerges from lack of capacity amongst both researchers and partners to adapt to the culture of the other. The main additional fail factor which we identified is around funding uncertainties which affected science policy engagement efforts.

Table 3.6 Empirical fail factors in science-policy engagement efforts as a specification or addition to hypothetical fail factors

Hypothetical fail factors (from Table 6)	**Empirical fail factors**	**Early warning signs / challenges**
Knowledge generated is not salient	Lack of demand for science-based solutions	Lack of commitment from decision makers to make science-based decisions and to establish better governance processes which are proactive rather than reactive.
		Change of priorities among decision makers (e.g. governments, industry bodies) due to external or internal changes.
		Low priority for climate change and related topics (e.g. gender and climate action in agriculture), where there is a lot of lip service to the importance of these issues, but still often not considered a priority.
		Lack of interest from intermediaries (e.g. commissioned consultants) in including research outputs.
	Lack of salience in research results	Research results do not address the needs of decision makers, due to a poor understanding of needs, or as results may be unclear and incomplete.
		Formats in which research results are presented (e.g. as a journal paper as opposed to a user focused tool) may not be suitable for decision makers.
		Analysis is often at a more general level, and more detailed analysis which can be taken up by individual organisations remain lacking.
		Failure to produce really ground-breaking knowledge that would capture partner interest.
		Lack of a business case for investing in recommendations provided to decision makers.
Lack of institutional capacity	Differences in organisational cultures	Timeframes of researchers and decision makers are not aligned, research processes are slow when compared to the needs of decision making, which creates a fundamental incompatibility.

	Poor engagement and communications	Limited or no engagement efforts planned and done.
		Poor communication of research results due to lack of communications support, training or skills.
		Not engaging supporting technical staff in addition to decision makers, as decision makers usually fall back on technical staff in their decision-making process.
	Lack of suitable partnerships	The policy-making process involves a number of different actors, and lack of strong partnerships with multiple actors, and poor collaboration amongst partners can cause efforts to fail.
		Lack of sufficient backing from development partners (including boundary partners, high level experts, specialists) to strengthen policy and implementation.
Adverse power dynamics.	Power dynamics	Researchers not powerful enough in decision making processes to retain interest in knowledge produced.
		Multiple (and sometimes competing) motivations and stakeholders involved in decision making processes.
		Conflicting priorities and interests within decision makers' organisations, which make it difficult to navigate.
		Efforts are focused on changing the way in which things are done, rather than use of specific tools.
		Resistance to issues such as gender equality in the context of climate action in agriculture. Gender equality inputs are often not considered serious or "real" policy issues.
	Competition from other research groups	Alternative options and competing efforts from other research groups.
	Funding uncertainties	Uncertain and variable funding which affects research and engagement efforts.
		Lack of/limited financing from national or international funding agencies for scaling out efforts.
		Trends in donor driven initiatives and funding, which influence the behaviour of key partners.

3.4.8 Fail factors contextualised in examples

The above sections are drawn from experiences of project leaders and coordinators. Through additional interviews with the CCAFS management, we identified concrete examples of failed science-policy engagement efforts, which help contextualise the above results. These examples are summarised in Table 3.7, together with the fail factors which led to efforts failing. It must be noted that adverse power dynamics and lack of institutional capacity are the two pre-dominant fail factors identified from the CCAFS management's perspective. This may be because in these examples, CCAFS management has taken a very pro-active role through their portfolio management function to ensure that research results are salient, credible and legitimate, complemented by support to form and develop partnerships. However, adverse power dynamics often affected the outcome, and in other cases the research partners chosen lacked the capacity or skills necessary to realise the outcome.

Table 3.7 Examples of failed science-policy engagement efforts identified through interviews with CCAFS management

Description	**Fail factor(s)**
Nigeria: CCAFS engaged with the government to develop a roadmap for expanding insurance across the agricultural sector, this was envisaged to benefit millions of Nigerian farmers. However, with a change in government, and the leadership within the Federal Ministry of Agriculture and Rural Development, efforts failed to realise the expected outcome.	Adverse power dynamics
India: In the state of Maharashtra, CCAFS worked with the state government and the Agricultural Insurance Corporation, to design index-based insurance products which would protect over 1 million farmers. These products were provided to farmers in two seasons, however, a subsequent change in policy led to the products being unviable.	Adverse power dynamics
Honduras: CCAFS worked to scale index-based insurance products informed through participatory inputs from multiple stakeholders. While feedback from stakeholders including the Ministry of Agriculture was positive, efforts failed to scale due to regulatory issues faced.	Lack of institutional capacity
Brazil: CCAFS initiated a project for sustainable beef cattle production and improved landscape management through improved technical options, territorial monitoring systems and public-private partnerships. However, this project was cancelled due to funding cuts and insufficient progress towards expected outcomes, which in turn related to the approach adopted by the project.	Funding uncertainties. Adverse power dynamics.
Mali: CCAFS initiated a project one of whose aims was to build capacity and to mainstream climate change into national agricultural and food security policy plans. However, while the project did deliver research outputs, it was insufficiently well-linked to national policy-making processes, so failed to realise the expected outcomes in terms of policy change in the country.	Lack of institutional capacity. Knowledge generated is not salient.
Global: CCAFS engaged in UNFCCC negotiations on agriculture, with the goal of informing a decision on agriculture at the 18th Conference of Partiers in Doha in 2012. However, the expected decision only came in 2017.	Adverse power dynamics
Global: In 2017, CCAFS endeavoured to put its index-based insurance work high on the global agenda including with key impact partners and in the UNFCCC. However, efforts failed as CCAFS was unable to position itself as a major player in this space.	Lack of institutional capacity

Global: CCAFS engaged with USAID to inform their strategies and investments around climate-smart agriculture (CSA). However, following changes in Government, the priorities of USAID shifted from CSA.	Adverse power dynamics
Kenya: CCAFS worked on developing a Nationally Appropriate Mitigation Action proposal for the dairy sector, but the submission of this proposal took longer than anticipated due to challenges in securing a lead applicant.	Adverse power dynamics
Asia-Pacific: CCAFS engaged with the Asia-Pacific Economic Cooperation (APEC) to inform a new APEC initiative on agriculture and climate change involving 15 countries. However, while a declaration was made, the initiative did not materialise.	Adverse power dynamics
South East Asia: efforts to scale up insights from climate-smart villages into large scale development programmes across the region did not achieve the expected scale.	Lack of institutional capacity

3.5 Discussion

The results provide detailed empirical insights into failed science-policy interactions, a hitherto underexposed field of study. Experiences with failure were derived from reports of interviewees and, therefore, might to some extent be idiosyncratic. Nevertheless, they do provide new insights into challenges and failures which go beyond the factors currently identified in the literature. These insights drawn from unsuccessful efforts not only show ‘what not to do’, but also how lessons can be generated systematically and how management can adapt to emerging failures in science-policy engagement efforts. In this section, we discuss the implications of the results for research and practice of science-policy engagement efforts.

3.5.1 Credibility, salience and legitimacy

The three principles of enhancing credibility, salience and legitimacy (Cash et al., 2003) have formed the basis of efforts to improve efficacy of science-policy engagement efforts. We hypothesised that the absence of these principles could lead efforts to fail. The results show that lack of credibility was not an important fail factor for respondents. While this is an important finding, science-policy engagement is context-specific, and the specific contexts within which respondents operate could have influenced this. In a previous study on success factors of CCAFS science-policy engagement efforts (Dinesh et al., 2018), it was found that the credibility of the CGIAR and its researchers was a key success factor. This may point to a broader perceived credibility for the organisation and explain why a lack of credibility was not faced by most respondents. From the responses of respondents who were faced with this issue, we gain lessons which can be useful to strengthen science-policy engagement efforts. This includes spending time and effort to build credibility, addressing complexity and uncertainty, and the production of case studies and quantitative data which can support engagement efforts.

Lack of salience on the other hand was found to be a key fail factor. However, this fail factor not only arises when efforts on the part of researchers and research managers to make outputs salient prove insufficient, but also when there is a lack of demand for salient knowledge. CCAFS has an emphasis on generating evidence salient to the needs of decision makers (Dinesh et al., 2018; Zougmoré et al., 2019), and this emphasis has enabled the programme to deliver successes which have been recorded in the literature (Westermann et al., 2018), but there are areas where this can be further strengthened, for example by improving dialogue on problem definitions/problem structuring to make results more relevant (Funtowicz and Ravetz, 1997; van der Hel, 2016), aligning the timelines of research and decision making, accommodating for changes in decision makers, and communicating and engaging better. Development of salient knowledge needs to start from true interaction with next users (i.e. the immediate next users of research rather than ultimate beneficiaries), as opposed to an approach of retrofitting existing knowledge and tools to needs, as this creates path dependence (Interview-C, 2019). In engaging next users, care must be taken to address criticisms of such engagement approaches, including the costs vs benefits and adverse power dynamics, (Oliver et al., 2019; Turnhout et al., 2020; Wyborn et al., 2019).

Lack of legitimacy was also not validated as a fail factor by respondents of our survey, and this may also be a context specific feature of CCAFS, where good practices around ensuring legitimacy have been noted in the literature (Vervoort et al., 2013; Zougmoré et al., 2019). We also considered issues around communicating uncertainty in relation to legitimacy, and found that a number of actions were taken to communicate uncertainty in a fair and balanced banner. However, as noted by Sarkki et al, management of uncertainty is considered important in relation to all three principles (Sarkki et al., 2015), and responses in relation to credibility also show the relationship between communicating uncertainty and the credibility of research outputs and institutions. The relationship between communicating uncertainty and salience has been studied by others (Bromley-Trujillo and Karch), and therefore communicating uncertainty is relevant in relation to all three principles.

3.5.2 Institutional arrangements and capacity

Appropriate institutional arrangements and capacity are key to ensure that knowledge leads to changes on the ground (Múnera and van Kerkhoff, 2019). In this context, lack of institutional capacity among partner organisations was identified as a fail factor (Table 3.1). The results show that it is not only absorptive capacity that needs to be enhanced, but also the capacity of researchers to do outcome-oriented research and engagement activities. For example, the role of partnerships is quite central to delivering outcomes, and this includes partnerships with boundary organisations, development agencies, government agencies, farmer organisations etc., and lack of suitable partnerships or non-performance of partnerships have caused efforts to fail. For example, in the Honduras example, developing different and more in-country partnerships could have been effective (Interview-B, 2019). This stems from a lack of capacity to develop and manage suitable partnerships. Although CCAFS has an emphasis on partnerships at the programmatic level, failure arises from the lack of the right partnerships in specific contexts. While this is difficult to pre-empt, as performance of partners may change over time, adaptive management, which enables revisiting partnerships in response to needs could be an effective strategy. Skills to develop partnerships also need to be fostered, as these tend to be different from research skills. As noted in the Mali case, where skills to develop partnerships may have been absent resulting in efforts not succeeding (Interview-C, 2019). Models of partnerships which have been tested in other contexts can also offer inspiration for CCAFS partnership building efforts (Dentoni et al., 2018).

While CCAFS has been successful in leveraging on the potential of science-policy engagement to achieve development outcomes (Dinesh et al., 2018; Thornton et al., 2017; Westermann et al., 2018), the degree to which the principles adopted at a programmatic level are operationalised varies, while there are projects which have taken this on board to deliver outcomes, there also remain projects/efforts which do not have effective science-policy engagement and communications strategies in place. CCAFS as a programme advocates dedicating a third of research efforts for engagement and communications (Dinesh et al., 2018; Vermeulen and Campbell, 2015), however a key reason for failure was that researchers did not have sufficient time to dedicate to engagement and communications activities, for example in the cases from Mali and South East Asia. Effective implementation of programmatic priorities, including through resource allocation and capacity building can help overcome this to a certain extent.

Limited institutional capacity on the part of decision makers has been identified as a fail factor. CCAFS does make efforts to build capacity, including emphasis on institutional strengthening (CCAFS, 2017), however, capacity gaps still exist among decision makers. Strengthening efforts to build capacity is needed, but capacity is to some extent the result of the political and knowledge system, and a concerted effort is needed beyond a single programme or institution, to build capacity of decision makers to respond to challenges of climate change. Research and decision making are two entirely different cultures, and while science-policy engagement offers a way for addressing these differences, deep cultural differences can cause efforts to fail. For example, the timeframes that both communities operate to are entirely different (Sarkki et al., 2014), and often impossible to reconcile. The role of knowledge brokers and translators can help bridge these differences, but a fundamental revisiting of organisational cultures is needed if both communities are seamlessly integrated in an ongoing science-policy engagement effort. In examples from Kenya and the UNFCCC, although efforts failed to achieve the expected outcomes in the expected timeframe, these outcomes were realised in later years, because of political and institutional factors involved.

Much emphasis has been put on co-production of knowledge and social learning to engage decision makers, however in the contexts which CCAFS works in, high turnover of decision makers was observed as a key challenge and a cause of failure. This points towards the need for engagement processes to go beyond individuals, and to be institutionalised to ensure longevity. However, weak institutional structures may deter implementation of such efforts in some contexts. Moreover, recent work by Turnhout et al., shows that in order for co-production to be transformative, it needs to address unequal power relations (Turnhout et al., 2020).

3.5.3 Navigating power dynamics

Power dynamics play an important role in linking knowledge to action (Clark et al., 2016b; Turnhout et al., 2020; van Kerkhoff and Lebel, 2006). In science-policy engagement efforts, researchers move outside the knowledge production process to enter the political realm, where power dynamics are crucial and navigation of these power dynamics may lead to success or failure in terms of achieving the expected outcome. Different approaches to engagement may be pursued, with varying implications to the empowerment of different stakeholders involved (van Kerkhoff and Lebel, 2006). From the perspective of researchers engaging in decision making processes, their power varies, for example for researchers participating in a process set by authorities, their power may not go beyond defining problems, whereas when there is formal organisation level engagement, researchers are more powerful, although not in a position to challenge the power of decision makers (van Kerkhoff and Lebel, 2006). This relative power that researchers hold in the engagement process can cause efforts to succeed or fail, for example, while working with APEC, an integration approach (van Kerkhoff and Lebel, 2006) was adopted to set a shared agenda, however due to political priorities at play and researchers not being a powerful enough player, these efforts failed to realise expected outcomes. This was also true in the cases of informing decisions of the Nigerian Government and that of USAID, where changes in Governments and subsequent leadership played a key role in defining priorities, and researchers were not powerful enough to challenge this power. These power relations could be reversed in the case of co-production processes established by researchers themselves, wherein researchers tend to hold more power, and there is need to ensure that other stakeholders are empowered (Turnhout et al., 2020; Wyborn et al., 2019).

In addition to the power play between researchers and decision makers, an additional perspective observed was the role of other competing researchers/research groups. There is often competition among research groups for 'their results' to inform decisions, and to have the ear of the decision makers. Such competition can be an external factor which affects the success or failure of engagement efforts. In the CCAFS context, such competition was not only observed from other research institutions, but also within the same organisation (Interview-B, 2019).

3.5.4 Funding uncertainties

The role of funding organisations and funding commitments in determining the priority accorded to science-policy engagement has been noted (Arnott et al., 2020; Sarkki et al., 2019). This crucial role of funding organisations and commitments also emerged during our study, and specifically, we found that changes to funding on an annual basis, makes it difficult for researchers to plan and execute multi-year engagement strategies, and has been an important fail factor. While adaptive planning on the part of researchers can help mitigate this to some extent, large scale changes to funding beyond the control of researchers can be detrimental. This can only be addressed through multi-year commitments and certainty from donors, which maximise the potential to address challenges. Funding uncertainties also extend beyond funding for engagement, to also include funding for implementing science-based decisions. Uncertain funding to implement and scale science-based solutions has also been identified as a cause of failure. However, while funding uncertainties have been a fail factor, it is also important to be cognisant of the fact that funding uncertainties should not be used as an excuse for other fundamental problems around project design and implementation (Interview-F, 2019). Examples are emerging of researchers grouping to address challenges of scarce resources (Sarkki et al., 2019), and similar models may also benefit CCAFS and other organisations.

3.6 Failing intelligently at the interface between science and policy

While we have identified the key causes of failure of science-policy engagement efforts in the context of climate action in agriculture, failing is inevitable as studies in other sectors have shown. Therefore, rather than endeavouring to entirely avoid failures, a conscious effort to fail intelligently is more desirable. Such an approach will enable researchers to improve the efficacy of their science-policy engagement efforts. Intelligent failure arises from thoughtfully planned actions, which are executed effectively, at a scale which is modest, in areas where lessons can be generated from such failures (Sitkin, 1992). This involves, taking cognisance of failures, learning from failure, and developing a culture around failing intelligently to improve and innovate (Cannon and Edmondson, 2005). In relation to science-policy engagement efforts in the context of climate action in agriculture, we propose the following steps to fail intelligently. These steps are inspired by Cannon and Edmondson (2005), and aim to apply the generic set of principles to science-policy engagement efforts:

1. **Plan for failures**: At the design stage, take cognisance of failures which may be experienced in the science-policy engagement process, and develop strategies to overcomes these. The fail factors identified in this paper offers researchers insights into potential challenges which may be faced, and can enable the development of appropriate mitigation plans.
2. **Minimise risks**: Where there is a possibility of failure, ensure that risks are minimal in terms of resources expended and time spent in science-policy engagement efforts.

3. **Design efforts intelligently for generating lessons, in success or failure**: Design science-policy engagement strategies intelligently, so that in the event that these strategies fail, they generate lessons which can enable researchers to navigate similar challenges in the future, for example in identifying early warning signs of failure (Leoncini, 2017).
4. **Make failures visible**: Record failures carefully, and foster a culture where failures are admitted early, and understood to be part of the culture of experimentation and innovation. This can be the most difficult step as it requires a change in organisational culture.
5. **Learn from failures:** Actively generate lessons from failures to improve the efficacy of science-policy engagement efforts.

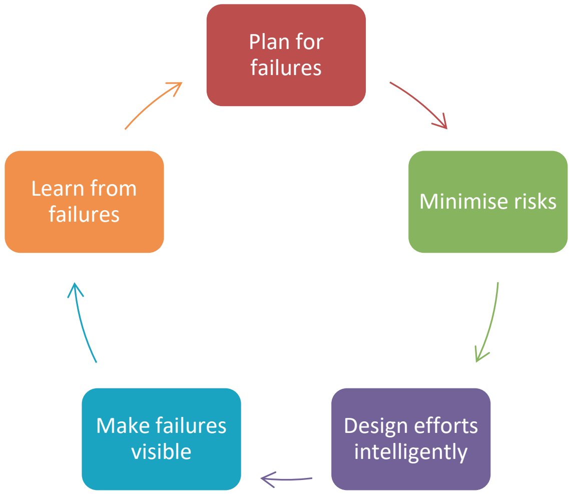


Figure 3.1 Steps for failing intelligently in science-policy engagement for climate action in agriculture

It must be noted that the applicability of these steps is context dependent, and in a highly competitive environment, some steps may be easier to implement than others. For example, in the CCAFS case, we noted that failure is a delicate subject overall, and most programme participants were not willing to share their experiences in our survey. This means that Step 4 would be the most challenging to implement in such a context. However, in most contexts, the right incentives and support from management would be crucial to empower researchers to learn from their failures in science-policy engagement.

3.7 Conclusion

We provide empirical insights into the challenges and failures faced in science-policy engagement efforts for climate action in the agricultural sector. By analysing failures rather than successes, we provide a perspective which has until now not been reflected upon in the literature on science-policy engagement. Meanwhile, for the literature on failure management, we provide insights from application of failure management concepts in the science-policy engagement context. Specifically, we have identified fail factors, which can be addressed to improve the efficacy of science-policy engagement processes. These include the lack of salience in research results, lack of institutional capacity, adverse power dynamics and funding uncertainties. Various dimensions of these fail factors and their relationship to the literature have been discussed, enabling future research and practice. Future research can shed light on context specific performance of the fail factors as well as identify additional fail factors. Efforts to capture user perspectives on failure of science-policy engagement efforts will also be valuable. However, research efforts should transcend disciplinary boundaries to offer fresh insights to address pressing knowledge needs.

To address fail factors identified in research management, we propose that capacity building efforts are undertaken, both within the research community and among decision makers to build buy in for science-based solutions. Priority should be accorded to build capacity of expert intermediaries and boundary spanners. Secondly, better matching of demand and supply of knowledge is needed, for example through the production of synthesis outputs in formats which are useful for decision makers. Platforms which facilitate matching of demand and supply can also play an important role. Thirdly, to address the power imbalances faced by researchers, efforts need to be taken to strengthen the position of researchers, through their technical expertise and clear communications. However, the knowledge system operates in different scales, and it is necessary to be cognisant of the diversity (Warghade, 2015). Principles of research funding, with its huge emphasis on success needs to be revisited to see failure as possible, as acceptable, and also valuable. Finally, an understanding of which factors fall beyond the sphere of influence of any given project is also valuable for those involved in that specific project. Even though external factors cannot be steered, they can still be adapted to; and moreover, individual researchers and projects can also work actively to extend their sphere of influence to bring factors that start as external within reach – something that may be especially feasible for projects that are supported over longer periods of time.

Our findings point towards redefining the role of the researcher (Turnhout et al., 2013). A researcher is no longer only a generator of knowledge, but a policy entrepreneur who identifies and accesses windows of opportunity, and as with all forms of entrepreneurships, both successes and failures can be faced in this path. However, as with entrepreneurship, intelligent failure (Edmondson, 2011) can enable researchers to learn from failures, generate lessons for the wider community and apply adaptive management strategies to be successful. The *How* on integrating learning from failures is key, as failures are often unreported, therefore a shift in our approach to research and research management, which values failures for their lesson learning function is needed.

In order address the challenges of adaptation, mitigation and food security, it is essential that knowledge sharing mechanisms are improved within the agricultural sector. This requires wider changes to the knowledge system, that is conducive of science-policy interfaces (Felt et al., 2016). In the absence of such a change, improved efforts of the research community will continue to deliver suboptimal result. Learning from failures can not only help improve practice at the level of the researchers but also address wider issues within the knowledge and political systems.

CHAPTER 4

A CHANGING CLIMATE FOR KNOWLEDGE GENERATION IN AGRICULTURE:

LESSONS TO INSTITUTIONALISE SCIENCE-POLICY ENGAGEMENT

This chapter is published as:

Dinesh, D., Hegger, D., Vervoort, J. and Driessen, P.P.J., 2021. A changing climate for knowledge generation in agriculture: Lessons to institutionalise science-policy engagement. *Frontiers in Climate*, *3*, p.42. https://doi.org/10.3389/fclim.2021.615463

4.1 Introduction

In its special report on Climate Change and Land, the Intergovernmental Panel on Climate Change (IPCC) has said that food security has been affected adversely by climate change and future food security is at risk from a warming climate (IPCC, 2019). Meanwhile, the report also highlights the opportunities for land-based actions to combat climate change and the need to accelerate knowledge transfer (IPCC, 2019). In 2015, countries submitted their Nationally Determined Contributions (NDCs), which form the basis of the Paris Climate Agreement intended to keep global warming to less than 2 degrees Celsius. These NDCs overwhelmingly prioritise agriculture as a sector for adaptation and mitigation actions (Richards et al., 2016; Strohmaier et al., 2016). 131 countries have indicated adaptation in the agriculture sector to be a priority (Strohmaier et al., 2016). Among developing countries, this priority is all the more distinct, with 93% of developing countries prioritising adaptation in the agricultural sector (Strohmaier et al., 2016). These priorities include actions pertaining to crops, livestock, fisheries and aquaculture, irrigation, water, knowledge transfer, diversification, soils, early warning systems, agroforestry, indigenous knowledge, financial mechanisms etc. (Richards et al., 2015), indicating that virtually all agricultural activities are at risk due to climate change.

In the context of climate change, many agree that new models of knowledge production with an emphasis on generation of societal outcomes are needed (Cash et al., 2003; Dinesh et al., 2018; Kläy et al., 2015; Popa et al., 2015; Sayer and Cassman, 2013; van der Hel, 2016). Such models will be crucial for adaptation in the agricultural sector, to enable countries to translate priorities set out in their NDCs into tangible actions which benefit rural communities. However, efforts to facilitate adoption of such actions at scale are affected by a number of factors. These include the enabling policy environment, institutional coordination and capacity, engagement among different stakeholders, research and development systems, and market development (Biagini et al., 2014; IPCC, 2019; Long et al., 2016; Lybbert and Sumner, 2012). Therefore, new models of knowledge production need to be developed, not only at the level of individual researchers or research projects, but also to be institutionalised to effectively address systemic limitations. In global environmental governance, the development of new institutions as well as the redesigning of existing institutions is a prominent need (Biermann, 2007; Young et al., 2008). Within the agricultural sector, experts have called for efforts to significantly change the approach to Agricultural Research for Development (AR4D) and to design transdisciplinary innovation ecosystems (Barrett et al., 2020; Herrero et al., 2020; Meinke et al., 2006; Steiner et al., 2020).

Global investment in agricultural research for development is significant. The World Bank has estimated that around USD 56 billion was spent on agricultural research and development in 2011 (Fuglie et al., 2020). Collectively over almost 50 years (1962-2011), it is estimated that over USD 1.1 trillion has been spent on public agricultural research and development alone (Fuglie, 2017). Ensuring that the significant public resources devoted to AR4D enable climate action in the sector therefore provides an opportunity to deliver enhanced societal outcomes from these investments. Among institutions developed for agricultural research and development, the CGIAR, originally the Consultative Group for International Agriculture Research (CGIAR), is a key player as the network of international agriculture research centres (Ozgediz, 2012; Pingali and Kelley, 2007), which invested USD 824 million in agricultural research and development in 2018, and about USD 60 billion over the past five decades in present value terms (Alston et al., 2020a). The CGIAR's focus on smallholder farmers in the global South - most often at the frontline of climate change impacts - makes it a key institution for adaptation in the agriculture sector, and Bill Gates, Co-Chair of the Global Commission on Adaptation and the Bill and Melinda Gates Foundation said, *"for poor country farmers, the CGIAR system is the only hope we have"* (Gates, 2019).

There is growing recognition within the CGIAR of the impact of climate change on its clientele (smallholder farming communities), and Table 1.1 (Chapter 1) outlines the evolution of climate change research within the CGIAR in the context of wider reforms. In this context, studying and improving the CGIAR's knowledge generation models in relation to climate change offers an opportunity to identify best practice for institutionalisation, and thereby enable the sector as a whole to more effectively support adaptation actions. As the international system for agricultural research, the CGIAR reform process has attracted the attention of various scholars (Byerlee and Lynam, 2020; Kamanda et al., 2017; Leeuwis et al., 2018; McCalla, 2014, 2017), and in addition to scholarly research, the reforms have also been reviewed by leading international experts as part of CGIAR's evaluation processes (Beddington et al., 2014; Birner and Byerlee, 2016). While Byerlee and Lynam (2020) have argued that the formation of the CGIAR is *'the major institutional innovation of the 20th century for foreign assistance to agriculture',* they note that in order to retain its leadership, longstanding organisational and funding issues will need to be resolved (Byerlee and Lynam, 2020). While the reform process brought greater impact orientation and coordination, it has also been critiqued for governance ambiguities, prioritisation of research, transaction costs and research quality (Leeuwis et al., 2018). The challenges of institutionalising new approaches to research within the CGIAR has also been noted (Douthwaite et al., 2017).

Over the past decade, climate change efforts within the CGIAR have been led by the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) which made a conscious shift from 'research in development' to 'research for development', by taking a theory of change approach to making research more outcome oriented (Dinesh et al., 2018; Thornton et al., 2017; Vermeulen et al., 2012a). CCAFS works in four flagship areas: 1) priorities and policies for Climate-Smart Agriculture (CSA); 2) Climate-smart technologies and practices; 3) Low emissions development; and 4) Climate services and safety nets. In addition to the flagships, two cross-cutting areas also exist, gender and social inclusion and scaling climate smart agriculture. Across the flagship areas, outcome targets have been set

(CCAFS, 2016), and it is envisaged that these targets will be met through projects under each flagship as well as synthesis and science-policy engagement activities. In 2019, CCAFS spent USD 53.6 million (CCAFS, 2020) in over 50 projects across all flagships. These projects mobilise not only the expertise from within the CGIAR, but also advanced research institutions, national agricultural research systems, and development partners. To ensure that the research results address the needs of target stakeholders, CCAFS has developed a regional approach, with programmes established in South East Asia, South Asia, East Africa, West Africa and Latin America. In each region, impact pathways have been developed in consultation with partners in the region (Schuetz et al., 2014). A matrix management approach is taken to design and manage projects, wherein projects are designed and managed jointly by flagships and regions, and this is at the crux of its model of 'research for development'. In this context, we seek to open up a new pathway for interdisciplinary research for development linking institutional design with science-policy engagement, to help conceptualise what impact-oriented AR4D would mean in an era of climate change. We do this by examining CCAFS' efforts to enhance credibility, salience and legitimacy in knowledge generation for its key stakeholders. We aim to provide insights relevant for theories of institutional design (e.g. Ostrom, 2011; Biermann, 2007; Young et al., 2008), not only for the benefit of the CGIAR, but also the wider knowledge system for agriculture under climate change, as there has been increasing focus on transforming knowledge systems to catalyse a transformation in food systems (Fanzo et al., 2020; Herrero et al., 2020; Klerkx and Begemann, 2020; Loboguerrero et al., 2020). We also aim to contribute to the literature on science-policy engagement, addressing a prominent knowledge gap, being the systematic empirical study of knowledge systems for sustainable development. While much conceptual work on this topic been done, the systematic empirical unpacking of 'what works' in different empirical domains is of a more recent date (Hegger et al., 2020). This paper adds to these emerging empirical examples an institutional perspective on how science-policy engagement efforts are institutionalised in a key international institution and a player in the knowledge system on agriculture and climate change. This also includes literature on boundary work drawing on multiple communities of expertise to support decision making in highly different contexts ranging from participatory R&D to political bargaining and earlier insights on boundary work within the CGIAR (Clark et al., 2016a).

To achieve the research aims, the following steps will be taken. Section 2 outlines our conceptual approach and methods. Section 3 presents the results. This is followed by a discussion (Section 4) and the conclusion (Section 5), focusing on key issues and commonalities as well as potential next steps.

4.2 Conceptual approach and methods

4.2.1 Conceptual approach: institutional analysis for AR4D

In their seminal (2003) paper, Cash et al. have coined the notions of credibility, salience and legitimacy as indicators of quality of knowledge for science-policy engagement efforts to inform societal outcomes (Cash et al., 2003). Credibility refers to the adequacy of scientific information, salience to its relevance to decision makers, and legitimacy the extent to which the information is considered to have been respectful of divergent views (Cash et al., 2003). These notions provide the foundation for improving research for sustainable development and resonate with CGIAR's interpretation of research quality, wherein the principles of relevance, scientific credibility, legitimacy and effectiveness are key attributes of quality of research (Belcher et al., 2015; ISPC, 2017). In an earlier, related, paper, Cash et al. (2002) propose strategies to institutionalise efforts to enhance salience, credibility and legitimacy in boundary organisations. These strategies have potential applicability in institutional design and reform in the context of climate change.

We use the success conditions based on Cash et al. (2002) and specify these to fit the context of climate change and agriculture in order to understand the patterns of interactions leading to enhanced credibility, legitimacy and salience in knowledge generation. These success conditions are shown in Table 4.1, where we have described, validated and operationalised these against the wider literature. Based on this process, the success conditions provide a conceptual starting point to study the CCAFS programme. The concepts proposed are not final and empirical research helps us to specify them.

Table 4.1 Framework for examining programme efforts to enhance salience, credibility and legitimacy (Adapted from Cash et al. 2002)

Success conditions	Description of the condition and outline of the assumed relationship with credibility, salience and legitimacy
Accountability	Research institutions are accountable to both sides of the boundary (i.e. research and action), helping ensure **legitimacy** (Cash et al., 2002; Guston, 2001; Kristjanson et al., 2009). This includes efforts to facilitate participation, transparency, evaluation of results and managing critique (Whitty, 2010)
Use of boundary objects	Actors involved in science-policy interactions co-produce boundary objects like assessment reports, models, maps and briefs, which enables research institutions to overcome the science-non-science divide and produce more **salient** research, and build **credibility** and **legitimacy** (Cash et al., 2002; Kristjanson et al., 2009).
Participation across the boundary	Research institutions effectively mobilise participation from both sides of the boundary to ensure the production of **salient**, **legitimate** and **credible** information to guide action (Cash et al., 2002; Clark et al., 2016a; Kristjanson et al., 2009; Popa et al., 2015).

Mediation and a selectively permeable boundary	Research institutions actively mediate to reduce the potential trade-offs and conflicts between increasing **salience**, **credibility** and **legitimacy** (Cash et al., 2002). It includes efforts to address concerns which can be practical, political or cultural. Meanwhile, having a selectively permeable boundary (Kislov, 2018) enables institutions to effectively engage across the boundary.
Translation	Research institutions translate research for users, helping enhance the **salience** of research results (Cash et al., 2002), enabling researchers and users to understand each other's' concepts, and address real world problems (Lang et al., 2012).
Coordination and complementary expertise	In addition to enhancing the scale and scope of research (Poteete et al., 2010), research institutions actively coordinate among entities with complementary expertise and mandates, provide more **salient**, **legitimate** and **credible** research results, leading to more harmonious actions (Cash et al., 2002).

4.3 Methods

We adopted a case study approach (Mills et al., 2010), and information on CCAFS' performance in relation to the criteria is gathered from the literature, independent external evaluations of the programme, and complemented with key informant interviews. The CGIAR has a focus on evaluation and impact assessment, therefore a number of evaluations have been conducted on CCAFS. These include an evaluation of the programme's themes by regions (Ash, 2013), a management and governance review (Robinson and Flood, 2013), a review of the low-emissions development activities (Smith, 2014), a review of work on climate services (Feinstein, 2014), a comprehensive external evaluation of the programme commissioned by the CGIAR Independent Evaluation Arrangement (Anderson et al., 2016), and two reviews commissioned by the European Commission (Pillot and Dugue, 2018, Jobbins and Pillot, 2013). These external evaluations have a number of findings which are relevant to our study, for example Anderson et al. (2016) examined CCAFS role as a knowledge producer and found that the programme has struck a balance between production of science-based knowledge and local application and scaling (Anderson et al., 2016). In another example, Smith (2014) focused on CCAFS work on low emissions development and found that the work was relevant to set objectives, effectively managed, sustainable and efficient. It noted that the scientific impact varied across outputs, and the development impact was likely to be moderate, although it was still too early to make a definitive statement (Smith, 2014).

We relied on external evaluations to ensure the greatest possible reflexivity. At the same time, the authors were in a good position to interpret the findings since the author team comprises researchers with multiple roles. The first author is employed by CCAFS but also has an academic affiliation and has conducted the current study as part of his latter work. The third author leads a project funded by CCAFS, but is an academic together with the second and fourth authors who are in the position to view the empirical field from critical distance.

12 key informant interviews with stakeholders were conducted using a semi-structured approach (Appendix 4). These interviews served to help interpret the findings from the document study, in particular to validate the way in which we linked the content of the evaluations to Cash et al.'s success conditions. In so doing, we tried to eliminate subjectivity to the greatest extent possible. Four of the interviewees were engaged in CCAFS's Independent Steering Committee (formerly the Independent Science Panel), three of the interviewees were engaged in the CGIAR's Independent Science and Development Council (formerly the Independent Science and Partnership Council), four of the interviewees were in the CCAFS and CGIAR management, as well as two external experts who have published on science-policy interfaces in the CGIAR[2]. These interviews give insight into decisions on institutional design and oversight, which would otherwise have been absent. The interviews were transcribed and key lessons corresponding to the criteria where identified by qualitatively analysing the transcripts. We also checked if inductive coding pointed us at additional success conditions, which were distinct from those already identified by Cash et al. (2002).

4.4 Results

In this section we present results from our literature review and interviews with key informants, wherein we examined the applicability of the success conditions presented in Table 2 in the CCAFS context.

4.4.1 Accountability

Key mechanisms to enhance accountability within CCAFS are the development of impact pathways, efforts to enhance transparency, external evaluations and impact assessments, and effective leadership. CCAFS has endeavoured to integrate accountability in its project design process through impact pathways for each project, which correspond to regional and thematic impact pathways at the programme level. These impact pathways ensure a route to societal impacts, while also ensuring that activities address major knowledge gaps (Schuetz et al., 2014). Participation of stakeholders from both sides of the boundary, i.e., researchers and decision makers are facilitated in the project design process (Schuetz et al., 2014), with the aim to ensure that research projects as part of the CCAFS portfolio address the needs of decision makers, as well as the knowledge gaps identified by researchers. Conformance to the project designs is monitored through monitoring, evaluation and learning efforts (Schuetz et al., 2017).

[2] Two of the interviewees have had multiple roles within CCAFS and CGIAR.

Transparency of the programme's efforts is provided through annual reporting as well as public facing pages of its projects through which individual projects' progress can be monitored. Evaluation of the programme's results have been conducted at different stages of implementation, including evaluation of thematic activities (Ash, 2013; Feinstein, 2014; Smith, 2014), management and governance (Robinson and Flood, 2013), and programme level evaluations (Anderson et al., 2016; Jobbins and Pillot, 2013; Pillot and Dugue, 2018). Efforts seem to have been made to address critique as each evaluation has received responses from the management, including on key actions to address recommendations. For example, following the 2016 evaluation (Anderson et al., 2016), the CCAFS management published its responses to all recommendations put forward by the evaluators (CCAFS, 2016). This includes a recommendation to increase its policy informing role, which the management agreed to do, focused on the development of NDCs as well as engaging with regional groupings in climate negotiations. Similar responses to other evaluations are also available.

In addition, a number of impact assessments have also been conducted, to evaluate impact of the programme's efforts to end users (Aryal et al., 2015; Gill, 2014; Hariharan et al., 2020; Murendo and Wollni, 2015; Reddy, 2015). The programme's accountability to facilitating outcomes also received favourable review in the programme-wide evaluation, wherein accountability within the CCAFS programme was considered to be enhanced as a result of the results based management and the associated approach of developing theories of change (Anderson et al., 2016). But, the review also called for further strengthening accountability by strengthening the theory of change and impact pathways at the regional and flagship levels (Anderson et al., 2016). The reviewers suggest that the assumptions and risks in these theories of change needs to be defined better and converted into hypothesis which can be tested during implementation (Anderson et al., 2016).

According to those involved in programme design, efforts to ensure accountability were crucial, as one of the interviewees who was part of the ISP noted, *"accountability was critically important for us and we took that very seriously at each of our meetings. I think we put the leadership team of CCAFS under enormous pressure early on in terms of the reporting requirements, and not just in terms of their financial reporting but also in terms of how people were appointed, how people were treated, what the culture was like in the organisation, and ultimately whether they were able to deliver on the promised results"* (Interviewee-T, 2020). This means that formal processes need to be complemented with informal processes and efforts (Interviewee-O, 2020), and a key aspect of ensuring this is through recruitment of suitable staff. The programme's approach of hiring staff accountable entirely to the programme as opposed to participating centres was found to be an effective approach (Robinson and Flood, 2013). Interviewees also noted the importance of competitive hiring (Interviewee-O, 2020), strategic leadership (Interviewee-W, 2020), incentives for researchers (Interviewee-X, 2020) and the developing country focus of staff. It was however noted that in maintaining accountability, CCAFS and the wider CGIAR can be affected by shifts in donor priorities (Interviewee-Y, 2020), trust deficits within

CGIAR governance processes (Interviewee-Y, 2020), and changes to governance processes (Interviewee-V, 2020). It was also noted that efforts to enhance accountability should ensure that the programme is accountable to the right stakeholders and the selection of stakeholders is not influenced by power dynamics, and bias towards current partners and research interests. (Interviewee-P, 2020; Interviewee-U, 2020). An example in the CCAFS context to enhance accountability is the focus on integration of gender equality within research, which was found to be under-developed in the 2016 review (Anderson et al., 2016), and subsequently a new strategy and leadership was brought in (Anderson and Sriram, 2019).

One of the interviewees identified an area of improvement to be accountability and interactions with funders, which can help make the funding environment more conducive for boundary work (Interviewee-T, 2020). This is important because in contrast to academia, scientists in the CGIAR need to be accountable to working for the poorest of the poor, while also publishing articles, and fundraising (Interviewee-Q, 2020), which requires the support of funders.

4.4.2 Use of boundary objects

Boundary objects developed in the CCAFS context include models, briefs, websites, conferences etc. which are targeted at practitioners. Key approaches to improve the use of boundary objects are to link these to science-policy engagement processes, capacity building efforts, and participatory knowledge production processes. While the use of boundary objects has not been explicitly noted as a strategy by CCAFS, this appears to be the case and the 2016 review noted that CCAFS produced a number of boundary objects, including briefs and info notes, working papers, reports and conferences (Anderson et al., 2016) next to specific participatory processes. CCAFS put quite a lot of emphasis on boundary objects and communication, as an interviewee on the programme's ISP noted, *"We needed to have credibility in the science community, so peer reviewed journals and articles were absolutely crucial without that we would not have succeeded but it's not sufficient of course. That's why we developed the policy briefs for example and other types of publications to reach out to other audiences"* (Interviewee-W, 2020). Interviewees found that CCAFS had been fairly successful in the use of boundary objects, particularly when engaging a target audience or process (Interviewee-O, 2020; Interviewee-W, 2020). This was approach was also reiterated by a science-policy expert interviewee, who said, *"to me there's an engagement process and in that engagement process it may be useful to use boundary objects as one of the tools in your engagement process. All of those things are part of what you need to do in order to be effective with your research"* (Interviewee-R, 2020). With regard to targeting specific processes and outcomes, the utility of boundary objects was perceived to be higher when focused at the supranational or national scales (Interviewee-S, 2020; Interviewee-V, 2020). Provision of capacity building and sequencing the production of boundary objects with participatory knowledge production was another important factor (Interviewee-T, 2020).

In producing boundary objects, the emphasis should not only be on briefs and info notes: events and processes are equally important. For example an interviewee noted *"an event, where the partner deeply buys into it, is much more successful than perhaps an info note produced solely by the research provider" (Interviewee-O, 2020).* Participatory scenarios were identified as another innovative boundary object (Interviewee-Y, 2020). In this case, CCAFS developed participatory scenarios with stakeholders (Chaudhury et al., 2013; Palazzo et al., 2017) and a review of these efforts (Carey, 2014) noted that the process had *"evolved from an academic approach to a bespoke product to meet the needs of the actors CCAFS wishes to engage". One of the interviewees also noted this, "I'd say one of CCAFS' great strength, is how to bridge that divide between science and policy and I would I think the scenario process is a really important boundary object for that"* (Interviewee-Y, 2020).

Producing boundary objects relevant to the context is not simple, and at times this happens in the midst of challenges, as an interviewee noted, based on her experience in the wider CGIAR, *"There's such a deep-seated attitudinal issue around needing to be in front, needing to be visible as an individual player and not as part of a bigger team"* (Interviewee-X, 2020). While this comment was not specifically about CCAFS, it is important to note that within the wider institutional landscape the need for attribution can be a risk to producing collaborative boundary objects. Capacity was another key challenge noted, as capacity to produce boundary objects cannot be taken for granted as scientists may not necessarily have the right skills to tell the story in a way that it appeals to the users (Interviewee-W, 2020). It was also noted that since the CGIAR has multiple entities producing boundary objects, users tend to receive too many boundary objects and information, and greater coordination and user orientation is needed within the CGIAR (Interviewee-U, 2020).

4.4.3 Participation across the boundary

Key mechanisms to improve participation across the boundary included a 'partnerships and participate' approach to deliver outcomes, regional engagement and engaging stakeholders from the beginning of the research process. The 2016 external evaluation noted that CCAFS was actively partnering with institutions on the delivery of knowledge (Anderson et al., 2016). The approach to project design, including the design of the impact pathways of projects, together with the matrix management approach involving flagships and regions facilitate participation across the boundary (Anderson et al., 2016). CCAFS also has a strategy in place for engagement and communications, to facilitate participation across the boundary (CCAFS, 2013), and the approach adopted in partner classification and delivery of results was identified as a good example in the CGIAR wide evaluation on partnerships (McLeod et al., 2017). While engagement of partners to deliver outcomes has been noted in the external review (Anderson et al., 2016), particularly at the regional level. Partners in turn perceived the outcome focus adopted by CCAFS as a clear competitive advantage (Anderson et al., 2016).

In the course of the interviews it was noted that participation is a key part of the CCAFS approach (Interviewee-W, 2020), which comes upfront in the research process (Interviewee-T, 2020). One of the interviewees observed that CCAFS in comparison to the wider CGIAR has done well on participation, but that performance across CCAFS was not uniform, with certain scientific leaders being far more open to equal relationships than others (Interviewee-X, 2020). Setting up regional programmes with senior leaders was perceived as a success factor (Interviewee-X, 2020). In addition to participation downstream with farmers and stakeholders, upstream participation, i.e. partnerships to achieve scale is important (Interviewee-V, 2020). One interviewee noted this as. *"partner and participate approaches"* (Interviewee-S, 2020), since the quality of the participation is enhanced through high quality partnerships that enable outcome delivery. One of the interviewees noted that within the CGIAR, the classic approach has been that partners came in at the end of the research process for scale, but CCAFS deviated from this approach and engaged partners right from the beginning, to understand their needs and co-designing research questions (Interviewee-X, 2020). This is important as balancing participation with strategic research is inevitable to manage tradeoffs of time and resources (Interviewee-Y, 2020). However, care must be given so that participation is fair and equitable and participants are actively engaged, and have a voice in deciding what the questions are (Interviewee-P, 2020; Interviewee-Y, 2020).

4.4.4 Mediation and a selectively permeable boundary

Key mechanisms for mediation include exchanges based on trust-based relationships and inputs from external experts. In terms of permeability of the boundary, facilitating transdisciplinary research was identified as a key mechanism, together with efforts to coordinate across institutions. Mediation as a tool to balance credibility, salience and legitimacy is not explicitly referred to in external evaluations of CCAFS. However, the interviews confirmed that while mediation as a tool has not been used explicitly (Interviewee-O, 2020), implicit mediation does occur in participatory processes which involve partners. These are addressed through trust-based relationships and exchanges with partners. As one interviewee noted based on his experience in science-policy engagement processes, *"in a political process, it's a negotiation process and you have to allow some things in order to get the bigger picture."* (Interviewee-S, 2020).

It was also found that trade-offs between salience and credibility were common when endeavouring to do high quality research and achieve outcomes at the same time (Interviewee-X, 2020). Potential tradeoffs between legitimacy and credibility were also highlighted (Interviewee-R, 2020). CCAFS has a matrix-based management approach in place, and this system seeks to provide a mechanism to mediate and achieve such a balance. An additional dimension to mediation which came out prominently in interviews was the internal 'science politics' within the CGIAR, wherein ongoing reforms and governance processes erode trust within the system, and have required mediation, for example by bringing in external experts (Interviewee-S, 2020). An interviewee noted, *"the CGIAR is one of* *the most over governed organisations that I've ever been involved in. And they haven't done that very effectively, a lot of the governance processes that are set up for some opaque reasons and often do not result in any sort of desirable outcomes"* (Interviewee-T, 2020).

In terms of the permeability of the boundary, there are two dimensions, boundaries among institutions and boundaries among disciplines. The CCAFS approach is one that enables permeability in both, however, within the wider institutional landscape, permeability of the boundary may cause overlap and competition among institutions. For example, within the international agriculture landscape, the CGIAR is responsible for research, FAO for policy and IFAD for funding, but in practice there is tremendous overlap among all these organisations and competition for funding (Interviewee-Y, 2020). With regard to disciplinary boundaries, an interviewee noted that this was a strength of CCAFS, *"they've always been very accommodating of those different strands and not just within the physical sciences but also between social science and the physical sciences. They were open to bringing in people from different backgrounds and give them an enabling environment in which they could make meaningful contributions."* (Interviewee-T, 2020)".

4.4.5 Translation

Key mechanisms for effective translation of research include ensuring a two directional process to secure stakeholder input and changing the culture to ensure a morelong term and impact oriented view of translation. Translation of research into usable formats is a big part of the CCAFS approach (Kristjanson et al., 2014), and a dedicated research area focused on translation, with emphasis on innovative research and communications, gender and social inclusion and future scenarios. The approach to translation was one wherein the users of research results were engaged at the outset to define the scope of research and thereafter throughout the research process (Kristjanson et al., 2014), which helps ensure salience of results. This is important as noted by one of the interviewees as translation needs to be a two directional process as opposed to scientists talking to users (Interviewee-P, 2020).

Challenges in this area included the timelines, wherein the impact was not visible during project cycles of 2-3 years, and difficulties in forming and maintaining non research partnerships. The interviews also noted that translation cannot be a one way process and needs to have the strong buy in of the target users, as an interviewee noted, *"translation needs commitment also from the target audience to read the research and a willingness to be informed"* (Interviewee-Y, 2020). This means that researchers need to have the right skills and capacity to be able to take that on (Interviewee-S, 2020). Cultural issues need to be addressed too, for example within the CGIAR communications is not understood as a tool for science-user engagement, communications is understood as a tool for advertising and fundraising (Interviewee-X, 2020). These deep seated cultural issues need to be overcome to be more effective in translation and this seems to have been the case in CCAFS (Interviewee-W, 2020).

4.4.6 Coordination and complementary expertise

Key mechanisms for effective coordination and mobilising complementary expertise include mobilising expertise from outside the CGIAR, more effective internal coordination of expertise, and a transdisciplinary approaches to address the needs of policy makers. At the time of CCAFS inception, CGIAR was lagging behind on global research for climate change as it had retained a very strong disciplinary focus, particularly on plant breeding without branching out into the broader areas that needed to be addressed in food systems and were important to policymakers (Interviewee-Q, 2020; Interviewee-T, 2020). CCAFS was initiated as a partnership between the CGIAR and the Earth System Science Partnership (now Future Earth) which had expertise in climate change research, which would complement the CGIAR's work (Interviewee-Q, 2020). CCAFS was being designed specifically to address policy needs, as one of the interviewees on the ISC noted, *"when we transitioned CCAFS from what used to be a challenge programme into a CRP under the new structure, we did that very much keeping in mind that we wanted to create an entity that firstly connects sensibly across all of the core disciplines within the CGIAR. But at the same time becomes really influential in providing evidence-based policy support at various levels. Because that's where clearly the need was"* (Interviewee-T, *2020).* Thus, CCAFS has the mandate to coordinate across the CGIAR on climate change issues and mobilise complementary expertise towards societal outcomes. In addition to the intra CGIAR role, CCAFS also has a focus on mobilising partners out with the CGIAR, where capacity is lacking within the system. The external evaluation noted that CCAFS has made progress with integration, but greater integration and linking is needed (Anderson et al., 2016). The approach to mobilising expertise from advanced research institutes in areas where the CGIAR system had limited expertise was noted as key feature (Anderson et al., 2016; Pillot and Dugue, 2018).

This coordination and mobilisation of complementary expertise is all the more relevant in the context of transdisciplinary research (Interviewee-R, 2020), and a former member of the ISC noted, *"everybody talks about the importance of inter and transdisciplinary research, but very few organisations know how to engender that and how to provide the supporting networks that are actually necessary for that"* (Interviewee-T, 2020). Often, institutional structures and incentives do not encourage such collaboration (Interviewee-O, 2020), and in the end the onus falls on *"a relatively small group of people that are really competent, dedicated and committed to the same outcome"* (Interviewee-O, 2020). This seems to have been the principle behind the design of the core CCAFS team (Interviewee-Y, 2020).

Coordinating climate change research in the CGIAR has not been an easy task, an interviewee associated to CGIAR management noted, "(Interviewee-T, 2020) *The prevailing view across CGIAR is that there is no need for any specialist knowledge on climate. Climate is not associated with any kind of specific skill sets or knowledge sets. And what this leads to is that climate change is used as an additional justification, a rationale for research projects. But then the research proposed is the same as it would have been, you know, prior to any awareness of climate change"*

(Interviewee-X, 2020). In this context, another interviewee noted, "my perception is that CCAFS focus on maintaining its coordination internally is very strong, much more than with the other CG centres or as a system" (Interviewee-Y, 2020).

4.4.7 Additional success conditions identified

In addition to insights about the success conditions from Cash et. al (2002), we inductively identified additional success conditions from the evaluations and during interviews, which were not contained in the initial Cash et al. framework.

(i) Role of leadership

Key mechanisms to enable effective leadership include selection of results oriented and strategic leaders, skills development, ensuring regional and national focus, funding allocation to enable efforts, and facilitating a shift in culture. It is evident from the evaluations and interviews that selection of the right leaders has been a key success factor in the CCAFS context. This means strategic leadership, as one interviewee noted, *"We need leadership that has a clear vision on an outcome-oriented approach. Clear vision that you should almost work backwards, you know what the target is and then put the research in place that's needed to achieve their target" (Interviewee-O, 2020)*. Good leadership can help to ensure that best practices are effectively institutionalised. Leadership should also be relevant to regional and national issues as noted by an interviewee based on the success of regional programs in CCAFS, *"I think one of the things that have helped with CCAFS, has been the permanent presence of the regional programme leaders in the regions"* (Interviewee-X, 2020). At the same time, it is important for leaders to steer clear of bias (Interviewee-R, 2020).

However, it may not be assumed that strategic leadership skills exist within the system, and where this is the case, skills development is important (Interviewee-S, 2020). In a complex environment such as that of the CGIAR, good leadership was noted as being, "*more bottom-up leadership, you are empowering people within the system to do good things as a leader rather than leading from the top down"* (Interviewee-S, 2020), and such skills need to be developed. Competitive hiring is another approach to fill skills gaps and secure leaders who are highly practical but also able to navigate the complexity of the CGIAR system, stakeholders and research challenges. Multiple interviewees engaged in CCAFS design and selection of leadership noted that leaders were selected based on their ability to navigate complexity and deliver results (Interviewee-Q, 2020; Interviewee-T, 2020; Interviewee-W, 2020). CCAFS also made a conscious attempt to recruit leaders from developing countries due to its focus on the Global South, this also helped, as an interviewee noted, *"I do think that with leadership, that does make a difference, If you come from a background where you identify with the partners"* (Interviewee-X, 2020).

Selecting good leaders is not sufficient, funding allocation needs to be in place to support leaders to take a strategic approach, as noted, *"I would say the most important thing to pay attention to is who controls the purse strings and who is accountable for making the results happen* *from those investments and expenditures"* (Interviewee-X, 2020). Supporting mechanisms, i.e. management is important to ensure that processes reflect the intentions at the governance level and making sure that people are on board and get the view (Interviewee-U, 2020). Institutionalising high-quality knowledge generation requires a shift in culture, and leadership and supporting mechanisms need to be in a position to support this shift, as a former member of the ISC noted, *"Culture eats strategy for breakfast, so you can have all the strategy in the world, but the culture will just squash it, so it is essential to have leadership that is absolutely consistent with the culture that you're trying to head towards"* (Interviewee-Z, 2020). Another interviewee also noted*, "I feel the problem is very deep in the culture of CGIAR and it's a way of working, and CCAFS has been quite radical in trying to break out of that CGIAR only model and be far more open to partnership, bringing in partners even to run parts of the programme, being very open to being an equal or even junior partner. And I guess that was established by the kind of attitudes across CCAFS leadership that could sort of break open that CGIAR culture a little bit"* (Interviewee-X, 2020).

(ii) Role of incentives

Key incentives can be provided at the level of funders (long term commitment to boundary work), programme level (linking project performance to achieving outcomes), and individuals (offering a career track for boundary scientists and incentives for achieving outcomes). One of our interviewees noted, *"in research as in many other areas of life, people have habits and it's very difficult to make them change their habits"* (Interviewee-Q, 2020). In order to change habits and realise impact, AR4D institutions should provide incentives to staff (Interviewee-P, 2020; Interviewee-X, 2020). Currently within the CGIAR the incentives for boundary work are limited, as an interviewee noted, *"There is no career track for the true boundary scientists or science policy interface people or whatever you want to call them. The people who are about research into action, who are there for the development part of AR4D. There are no jobs and that's zero, it's not taken seriously at all and is considered to be a kind of an add on, done by the scientists."* (Interviewee-X, 2020). The CGIAR has been very dominated by crop breeding as a legacy of the green revolution (Interviewee-U, 2020), but there are examples of incentives being established to generate greater engagement in other institutions (Interviewee-S, 2020), which can offer lessons to the CGIAR.

Incentives are needed at the programmatic level from funders, as one of the challenges noted in the interviews was the changing expectations of funders and the unpredictability in funding cycles as one interviewee noted, *"CCAFS did have influence and managed to get agriculture on the global agenda on climate change. I think it's one of those major breakthroughs, but it has not been very effective in engaging the funders of the CGIAR in such a way that there would be comfortable to continue with that model"* (Interviewee-T, 2020)". The current phase of CGIAR reforms are therefore going in the direction of funders wanting more line-of-sight in terms of investment and the outcomes and results, but the interviewee noted, *"this is going against the very nature of a boundary organisation because in a boundary organisation, you actually don't have* *that clear line of sight and often the attribution of those outcomes is incredibly difficult because so many other factors are involved in it"* (Interviewee-T, 2020). At the level of individual scientists, incentives can be offered through annual appraisals, salary levels etc. (Interviewee-X, 2020). An example that was highlighted from CCAFS was the approach to reporting and evaluating outcomes (Interviewee-X, 2020), which was established early on in the programme and results were a key factor that determined performance of projects and associated staff (Interviewee-O, 2020). Incentives should also go beyond rhetoric, as one interviewee noted, *"there's a lot of rhetoric about partnership, in reality we usually have to do it on a shoestring and I think that's one of the key problems that CCAFS is also experiencing"* (Interviewee-T, 2020).

4.5 Discussion

4.5.1 Success conditions for institutionalising efforts to enhance salience, credibility and legitimacy

Based on the results, which illustrate how the Cash et al. (2002) principles relate to CCAFS in the context of wider CGIAR reforms, we revisit the success conditions. Our results indicate broad applicability for these success conditions in efforts to institutionalise high-quality knowledge generation that enhances salience, credibility and legitimacy, thereby supporting science-policy engagement efforts. However, we also identified a need to specify the conditions for the domain of climate change, agriculture and food security and we identified additional success conditions through the CCAFS case study, which pertain to leadership and incentives. These point to the need to extend Cash' et al.'s original framework. Cash et al. (2002) do allude to the importance of leadership in the context of accountability, when leaders are chosen to be accountable to both sides of the boundary, but our results show that the role of leadership goes beyond being accountable, to ensuring that knowledge generation also enhances credibility and salience, manages trade-offs and supports science-policy engagement efforts. The effectiveness of empowered and competitive leadership, and indeed the success conditions identified by Cash et al. (2002) will also depend on the incentive structures which are in place, and this is the second additional success condition that we have identified. In Table 4.2, we revisit the success conditions proposed at the outset, together with additional success conditions identified from the results. Using this framing, we have identified key empirical lessons for institutionalisation of each of these success conditions.

Table 4.2 Success conditions and lessons for institutionalisation

Success conditions	Key lessons for institutionalisation
Accountability	Formal systems for developing theories of change and impact pathways are important but need to be complemented with informal efforts which rely on individual researchers and research leaders.
Use of boundary objects	Boundary objects need to be linked to impact pathways, partners, and policy-engagement processes to realise maximum impact. Focus should not only be on boundary objects but also boundary processes.
Participation across the boundary	The quality of participation can be enhanced if combined with partnership efforts, i.e., an approach to partner and participate. Participation should be fair and equitable, enabling stakeholders to have their say in the process.
Mediation and a selectively permeable boundary	Efforts must be taken to manage trade-offs between salience and credibility which may arise in a negotiation process. Mediation also becomes essential in the 'science politics' space especially in a complex institutional environment such as the CGIAR.
Translation	Translation should be a two-way process, with the target audience engaged early on in the process.
Coordination and complementary expertise	Establish incentives which promote efforts to coordinate and mobilise complementary expertise.
Leadership	Identify appropriate leadership and empower leaders to change culture. Develop leadership at the regional level for better engagement with stakeholders.
Incentives	Establish incentives for science-policy engagement efforts that enhance salience, credibility and legitimacy. This can be through linking performance with delivery of outcomes.

4.5.2 Creating an environment for 'enlightened' boundary work

In 2011, the global agricultural research and development expenditure was USD 56 billion (Fuglie et al., 2020), in the same year, CCAFS annual budget was only USD 62 million (CCAFS, 2011a). Therefore, for lessons derived to be institutionalised at scale, greater commitment from research funders and leadership is needed. As one of the interviewees noted, *"It's hard for isolated project outputs to get traction in the policy space. It needs a broader more cultivated space if you like a more fertile ground that's been cultivated more at the programmatic or institutional level"* (Interviewee-Z, 2020). In endeavouring to drive changes to the wider knowledge system, researchers need to be cognisant that they are in the 'science in politics' space, and without enormous commitment on their part, they end up, intentionally or not, serving the already empowered in the globalisation of food systems. Clark et al (2016) provides a useful framework on how boundary work can support ‘enlightenment’, decisions, and negotiations (Clark et al., 2016a). Enlightenment is framed as being about advancing basic understanding around key issues without concerns for short term application (Clark et al., 2016a), and mobilises multiple disciplines and thus true integrative research and development. While efforts within CCAFS focus on the use of knowledge to support decisions and negotiations, a greater focus on this kind of enlightenment is needed across the knowledge system. In the context of AR4D, effective science-policy engagement efforts can be found at the level of individual projects or programmes, but there is a need to go beyond these in order to reach the enlightenment stage.

As science-policy engagement moves from informing decisions and negotiations in the short term to a systematic approach to enlightenment, research efforts will be characterised by enhanced credibility, legitimacy and salience. At this stage, the roles of different actors which are currently clearly differentiated, e.g. knowledge producers, intermediaries, users etc., may merge. In the CCAFS case, we do indeed see these roles merging, with the same institution producing knowledge, translating it, and facilitating partnerships for greater uptake. While the advances in research on the roles of institutions which have specialised roles is welcome, the Cash et. al (2002) principles provide a helpful framing for institutions which may have multiple roles. As an interviewee noted, *“what you're aiming for is that sweet spot where a very well thought out and delivered theory of change comes together with excellent leadership capabilities, a really strong vision, and with that ability to engage a whole range of different stakeholder communities” (Interviewee-T, 2020).* Such blurred boundaries need to be taken into account also for the CGIAR reform processes, to enable the CGIAR to more effectively deliver outcomes. As one of the interviewees noted, “*We now understand that there are multiple kinds of boundaries and it's quite likely that it's different kinds of boundary work, still guided by the notion it's a two-way exchange, still guided by the notion of accountability and so on.”* (Interviewee-P, 2020). Therefore the emphasis needs to be on enabling boundary work within the institution, through institutional arrangements, norms, and procedures to support evidence-based policy making (Cash et al., 2002). Getting the institutional arrangements right, i.e. boundary settings (Mollinga, 2010) is crucial for the production of high-quality knowledge that enhances salience, credibility and legitimacy.

To catalyse institutional reform at scale and move toward enlightenment for science-policy interactions, efforts are needed in the wider institutional landscape for AR4D. Firstly, a shift in institutional governance which promotes a culture of evaluation and reflexivity amongst actors’ is important. Such a culture can be achieved through strategies including facilitating participation, transparency, evaluation of results and managing critique (Whitty, 2010). Our interviews show that the CCAFS governance mechanisms placed a huge emphasis on accountability, but within the wider CGIAR, trust deficits were noted in governance processes, which can undermine efforts to ensure accountability. A multi-scale approach to accountability (project, programme, institutional), can help enhance legitimacy of knowledge produced over and beyond an individual project or researcher.

We find that that several of the success conditions proposed by Cash et al. (2002): the use of boundary objects, participation across the boundary, mediation and translation, are not universal in applicability. Their applicability is dependent on the context, linking to policy engagement efforts and goals. To facilitate the development of context-specific approaches, institutional governance mechanisms need to foster a suitable environment where efforts to achieve impact are valued and incentivised, and capacity and skills are developed to enable researchers to make this shift.

The leadership of AR4D institutions needs to show commitment to knowledge generation which is credible, salient and legitimate, helping advance policy outcomes and impact on the ground. Such leaders need to be identified and appointed through competitive hiring processes, empowered to make decisions, and bring an entrepreneurial approach to science-policy engagement and achievement of outcomes. In the CCAFS context where the focus is on the Global South, regional leaders and those with developing country experience was found valuable. However, care must be taken so that the leaders thus selected are not overly involved in policy making processes causing research efforts to be biased.

Cash et al. (2002) have proposed coordination and complementary expertise as a key strategy. In the context of climate change adaptation in agriculture, this becomes all the more pertinent, and there is a need to break silos which may exist to make generate high quality and usable knowledge for decision makers. Strategies to do this can include developing partnerships, building transdisciplinary teams, and offering incentives for transdisciplinary work, which corroborates findings derived in the context of spatial climate adaptation in the Netherlands (Hegger and Dieperink, 2014). These have applicability in the CGIAR as well as other transdisciplinary research institutions operating to help adapt to climate change. These efforts can improve interactions among stakeholders, leading to better outcomes for salience, credibility and legitimacy.

The actions which have been highlighted here imply a change in culture within AR4D institutions, and this culture change needs to underpin actions as institutionalising high quality knowledge generation for climate change is not just about policies and procedures within an institution but about changing the cultural foundations to address climate change.

4.5.3 Opportunities for institutional analysis

The lessons on institutional mechanisms to enhance salience, credibility and legitimacy have implications for theories on institutional analysis in the context of institutional design and reform. The Institutional Analysis and Development (IAD) Framework developed by Ostrom et al. (Ostrom, 2011; Ostrom et al., 1994), is a useful framework to unpack the lessons for institutional design. Within the context of climate change impacts on agriculture, which enhances the risk of resource poor rural farmers, institutional arrangements are crucial to support farmers in climate change adaptation. Action research on climate change, agriculture and food security such as that conducted by CCAFS may be viewed as an '*action arena*' for institutional design. The CGIAR as the international entity responsible for agricultural research and through its ongoing reform to address climate change may be considered to be the '*action area*', which involves actors in this area including the CGIAR leadership, governance processes, funders, and users. With the CGIAR's emphasis on enhancing credibility, salience and legitimacy, as acknowledged by its interpretation of research quality (ISPC, 2017), institutional analysis of this arena and area, and effective institutionalisation of success conditions identified, offer a major opportunity to advance theory and action. The IAD framework has been developed to study institutions in different contexts (e.g. (Nigussie et al., 2018)), but its application to knowledge production could offer new insights for theory and practice.

4.6 Conclusion

This chapter focuses on a pressing knowledge gap: the need for more systematic empirical studies into the institutional design of knowledge action systems in the field of climate change and agriculture. We find that the success conditions proposed by Cash et al. (2002) are relevant to the CCAFS context, although CCAFS as a programme was not designed using these as the basis. We see this as an indication that the success conditions are useful guidance for the design and reform of institutions to enhance their ability for science-policy engagement and to deliver societal outcomes. However, though our analysis shows the strengths of the success conditions and their ability to enhance salience, credibility and legitimacy, these success conditions can be strengthened through the addition of two additional conditions - leadership and incentives. These were found to be crucial in the CCAFS case.

The refined success conditions for institutional design can help advance literature on science-policy engagement, offering perspectives on institutionalising efforts. We have expanded empirical studies of science-policy interactions, offering practical perspectives and applied it to an issue area that is in urgent need of more and more systematic attention of scholars, namely AR4D. While papers which laid the foundation for studying science-policy interactions including Cash et al. (2003) and Clark et al. (2016) draw on CGIAR case studies, the sector has been understudied, and we seek to further build on these foundations offering fresh perspectives around institutionalisation. These perspectives on institutionalisation also draw upon and contribute to the literature on institutional analysis and development. Our in-depth study of CCAFS has also led to novel insights on how to create an environment conducive to high-quality knowledge generation. It would be useful for future research to pursue such in-depth and interdisciplinary studies in other domains and issue areas.

The success conditions also have practical application in the design and reform of institutions for AR4D. Specifically, the CGIAR is now going through another round of reforms, which will see it transition to ‘One CGIAR’ a more cohesive international institution with climate change as one of the key priorities. The fact that the principles also conform to the CGIAR perception of research quality further enhances their credibility to be applied in institutional design for agricultural research for development under climate change. Applying these principles in the CGIAR reform process can further enhance the CGIAR’s ability to advance action in the context of climate change. Moreover, addressing challenges within the CGIAR for applying these principles including trust deficit, accountability, transaction costs etc., can help the reform process. These lessons also have applicability in the reform of other institutions, amidst the growing call to transform agricultural innovation systems (Fanzo et al., 2020; Klerkx and Begemann, 2020; Steiner et al., 2020). This requires a systemic shift in the institutional landscape, to create a suitable environment to apply the success conditions, by creating a culture of evaluation and reflexivity amongst actors, building capacity and skills to undertake science-policy engagement, transformative leadership that emphasises boundary work, and transdisciplinary research to address climate change issues.

CHAPTER 5

ENACTING THEORIES OF CHANGE FOR FOOD SYSTEMS TRANSFORMATION UNDER CLIMATE CHANGE

This chapter is published as:

Dinesh, D., Hegger, D.L.T., Klerkx, L., Vervoort, J., Campbell, B.M. and Driessen, P.P.J., 2021. Enacting theories of change for food systems transformation under climate change. *Global Food Security*, *31*, p.100583. https://doi.org/10.1016/j.gfs.2021.100583

5.1 Introduction

In recent years, there have been growing calls for a transformation in food systems. These calls have come from researchers, businesses, policymakers, civil society, amongst others. Various reports have highlighted this in the global arena (Pharo et al., 2019; Schmidt-Traub et al., 2019; Searchinger et al., 2019; Steiner et al., 2020). These calls for transformation are particularly relevant in the context of climate change, as food systems are responsible for a third of global greenhouse gas emissions from human activity (Crippa et al., 2021) and growth in agricultural yields may be affected up to 30% as a result of climate change, with the world's over 500 million small farms worst affected (GCA, 2019). Meanwhile, the world is not on track to eliminate hunger and 690 million people are undernourished while obesity is growing (FAO, 2020), even as 17% of food produced is wasted (Forbes et al., 2021), which shows inequities within food systems. The concept of transformation has different interpretations (Feola, 2015), but in common is a focus on fundamental changes that realise benefits for the environment and human well-being (Patterson et al., 2017), also referred to as 'system innovation'. System innovation is about comprehensive and co-evolving technological, institutional and social innovations which go beyond incremental innovations that optimise current systems but are aimed at radically reconfiguring systems (Barrett et al., 2020; Dentoni et al., 2017; Elzen and Wieczorek, 2005; Leeuwis et al., 2021; Meynard et al., 2017). Such system innovations may take several decades. In this paper, with the focus on climate change and food systems, transformation is seen as a change in at least one third of the inputs or outputs/outcomes of food systems, within 25 years or less (Vermeulen et al., 2018), as a result of system innovations.

Innovation processes (particularly system innovations) are thus key in catalysing a transformation in agriculture and food systems (Augustin et al., 2021; El Bilali, 2019; Leeuwis et al., 2021), and the literature indicates that for transformation it is important to be cognisant that innovation follows or is guided by directionality (Leach et al., 2020; Pigford et al., 2018). Such directionality of innovation comprises a certain value orientation (related to a certain problem framing and envisioned solution space – see (Wanzenböck et al., 2020)), and that can be enacted through different 'bundles' of technological, social and institutional innovations connected to transformative visions and concepts (Barrett et al., 2020; Klerkx and Begemann, 2020; Leeuwis et al., 2021). Such transformative visions, technologies and concepts include for example agroecology, digital agriculture, vertical farming, cellular agriculture, and many more (see e.g. (Herrero et al., 2020; Pigford et al., 2018)), embodying different pathways to and envisioned outcomes of transformed food systems in terms of inclusive growth, social justice, resilience to climate change, biodiversity and other contributions to sustainable development (Chiles et al., 2021; Hebinck et al., 2021; Herrero et al., 2021; Klerkx and Rose, 2020; Zurek et al., 2021). Calls to transform food systems are accompanied by calls to transform knowledge and innovation systems (Barrett et al., 2020;

den Boer et al., 2020; Fanzo et al., 2020; Fazey et al., 2020; Kok et al., 2019; Loboguerrero et al., 2020; van Bers et al., 2019) so that these better support food systems transformation and become 'mission-oriented' (Klerkx and Begemann, 2020). Mission-orientation of knowledge and innovation systems has become more prevalent recently in academic thinking and policy action and is about how innovation is framed in terms of its organisation, goals and purpose in view of systems transformation (Schot and Steinmueller, 2018). In the context of systems transformation (both in agriculture and food systems and for other systems such as energy, mobility, etc.), it has been argued that knowledge and innovation systems, beyond having a focus on linear technology transfer or orchestrating innovation for economic growth, need to be more explicitly supporting systems transformation and thus more strongly contemplate directionality towards this goal (Schot and Steinmueller, 2018; Pigford et al., 2018; Hall and Dijkman, 2019; Klerkx and Begemann, 2020; Leeuwis et al., 2021). Knowledge systems are made up of different players that generate, transform, transmit and store knowledge (Foray, 1997), while innovation systems take a wider lens and include the policies, institutions, cultural factors and power dynamics that more broadly play a role in the development and adoption of a novel technology or practice (Klerkx et al., 2012), e.g. related to resources exchange for innovation and creating of legitimacy for new technologies and practices. Thus, knowledge systems are an important part of innovation systems.

Transformation of these knowledge and innovation systems is particularly relevant in food systems, as around USD 56 billion is spent every year on agricultural research and development (R&D) (Fuglie et al., 2020), but they are sometimes focused on incremental as opposed to transformative change (Hall and Dijkman, 2019). Therefore, reorienting these investments to accelerate the transformation in food systems under climate change is a major opportunity (Steiner et al., 2020). There are growing calls to donors to double the investment into agricultural R&D (Alston et al., 2020b) and to agricultural development as a whole (Laborde et al., 2020). However, several issues have been identified, especially in public agricultural research systems including poor scaling logic and directionality, lack of understanding of the role of the private sector, misleading narratives, short term funding cycles, fragmentation, poor evidence base to support transformation, insufficient focus on novel approaches and mission orientation (Hall and Dijkman, 2019; Klerkx and Begemann, 2020; Steiner et al., 2020). Therefore, there is an imperative to transform knowledge and innovation systems, in the absence of which a transformation in food systems will remain a distant dream as several connected changes are needed to break out of lock-in and path dependency situations (Conti et al., 2021; Leeuwis et al., 2021). Hence, here several bundled or coupled system innovations are needed (Barrett et al., 2020; Elzen and Wieczorek, 2005; Leeuwis et al., 2021; Meynard et al., 2017) in which both the food system and the knowledge and innovation system are simultaneously restructured and transformed (den Boer et al., 2020; Kok et al., 2019; Pigford et al., 2018)

Several recent studies connected to global agricultural research for development establishments, intended to inform policies on food systems transformation, have focused on the 'What', for food systems transformation (Barrett et al., 2020; Campbell et al., 2018; Herrero et al., 2020; Loboguerrero et al., 2020). For example, echoing earlier notions from agri-food innovation systems and transitions studies on the co-evolution of technology, practices and institutions (El Bilali, 2020; Kilelu et al., 2013; Klerkx et al., 2012; Leeuwis et al., 2021; Melchior and Newig, 2021), Barrett et al. (2020) have highlighted the importance of socio-technical innovation bundles for food systems transformation, Herrero et al. (2020) have identified innovations with transformative potential, and Campbell et al. (2018) and Loboguerrero et al. (2020) have identified priority areas for a transformation. However, a key knowledge gap remains around the 'How', i.e. how can a transformation be actioned based on priorities identified by prior work, and what does this mean for knowledge and innovation systems? Our research aims to address this knowledge gap, based on an assessment of stakeholder perspectives from those involved in agricultural research for development (AR4D). We have taken a theory of change approach to fulfil our research aim, using a theory of change proposed by Campbell et al. (2018), as part of the global initiative, 'Transforming Food Systems Under a Changing Climate'[3], which brought together over 100 organisations to develop a vision and action agenda for transformation. Section 2 introduces this theory of change (ToC) and Section 3 the methods. Section 4 subsequently examines the ToC with inputs from 262 key stakeholders, ranging from researchers, intermediaries, practitioners and users themselves. We enrich the priorities proposed by Campbell et al. (2018), further interrogate the findings with the literature to identify the next steps needed to transform food systems, using innovation as the key lever for change in Section 5 before concluding the paper in Section 6.

5.2 A theory of change to catalyse a transformation in food systems under climate change

A Theory of Change sets out an impact pathway for efforts to reach a logical set of outcomes or impacts based on the experience and expertise of those undertaking efforts (Thornton et al., 2017). The global initiative, 'Transforming Food Systems Under a Changing Climate' has produced several outputs in addition to its flagship report (Steiner et al., 2020). These include peer-reviewed and grey literature on transformation of food systems. A key paper that set out the vision was Campbell et. al (2018), which proposed a ToC for a transformation of food systems, which envisages transformative action being taken in eight key areas: 1) strong farmer organisations and networking; 2) climate-informed advisories and early warning; 3) digital agriculture; 4) climate-resilient and low-emissions practices and technologies; 5) prioritisation and pathways of change; 6) credit and insurance; 7) expanded private sector

[3] https://www.transformingfoodsystems.com/

activity and public-private partnerships, and 8) capacity and enabling policy and institutions (Campbell et al., 2018). These priorities set out by Campbell et al. (2018), have been central to the development of the initiative, and Thornton et al. (2018) set out likely outcomes across each of these eight areas. Moreover, commissioned reports and related papers on specific action areas have also been produced as part of this initiative such as (Herrero et al., 2020; Millan et al., 2019; Rawe et al., 2019; Stringer et al., 2020; Vermeulen et al., 2020).

In line with emerging experience in AR4D contexts, practitioners are using the ToC to develop context-specific approaches to food systems transformation, e.g. the Global Commission on Adaptation (Loboguerrero et al., 2018; Thornton et al., 2019) and the Green Climate Fund (GCF, 2020). Given the growing convergence between the scientific and practitioner communities around these elements, we proposed this theory of change to the advisory committee of the 5th Global Science Conference on Climate-Smart Agriculture (CSA), as the framework for designing the biennial conference that brings together the community working on interrelated issues of climate change, agriculture and food security. The committee, which was composed of scientists and practitioners, reviewed the theory of change, and based on their deliberations, a set of six refined elements were finalised as themes of the conference. These six themes are shown in Figure 5.1, which are based on Campbell et al. (2018) and is the adapted theory of change we applied in this study. The elements of the theory of change are closely interlinked, and a transformation is envisaged as a coordinated set of efforts across these elements.

Figure 5.1 Theory of change for transforming food systems under climate change, based on Campbell et al. (2018)

5.3 Methods

In essence, we introduced the theory of change proposed by Campbell et al. (2018), in the context of the 5th Global Science Conference on CSA, refined it based on inputs from the advisory committee, resulting in the revised framework (Figure 5.1), which represents the current mainstream reasoning of professionals working on climate change, agriculture and food security. We interrogated the framework with conference participants through thematic discussions and a survey (Appendix 5). We also secured participants' inputs beyond the framework through open-ended questions and built on these results based on the literature and propose ways forward to action a transformation in food systems.

The biennial Global Science Conferences on Climate-Smart Agriculture (CSA) bring together stakeholders working at the interface of climate change, agriculture and food systems issues. The first such conference was held in 2011 in the Netherlands, the second in 2013 in the United States of America, the third in 2015 in France, the fourth in 2017 in South Africa, and the fifth conference in 2019 in Indonesia (GCSA, 2019). The 5th conference had a specific focus on transformation of food systems and applied the framework (Figure 5.1) in its design. This was done by making each element in the framework a theme of the conference, and contributions were secured through an open abstract submission process, thematic discussions were led by experts on each theme, and internationally renowned experts were also invited to make contributions along these themes. The conference brought together 410 stakeholders from over 200 institutions, based in 60 countries, thus bringing a wide cross-section of stakeholders (Dinesh, 2019).

The key stakeholders in the knowledge and innovation system may be grouped into researchers, practitioners and policymakers (Ingram, 2018; McCullough and Matson, 2016; Pingali and Kelley, 2007). We categorised conference participants into four categories: 1) primary knowledge producers such as CGIAR centres and programmes, advanced research institutions, National Agricultural Research Systems (NARS); 2) knowledge intermediaries such as United Nations agencies, Non-Governmental Organisations, and consultancies; 3) knowledge users such as Government agencies, farmer organisations, and investors; and 4) beneficiaries of knowledge such as farmers and businesses that benefit from applying knowledge generated which reach them through intermediaries and users of this knowledge. Besides being knowledge producers, intermediaries, users and beneficiaries, these actors also fulfil wider roles in innovation systems, e.g., setting innovation policies, fostering innovation networks and platforms, and providing financial resources for innovation (Klerkx et al., 2012). We undertook a survey with the participants of the conference (see Appendix 5),) and received 262 responses. 66% of the respondents categorised themselves as primary knowledge producers, 16% as intermediaries, 15% as users, 2% as beneficiaries, and the remaining categorised themselves as other. 19 of the respondents also indicated secondary categories in addition to the primary categories.

The responses have been analysed and results are presented in this paper. We complemented this with participant observation (Guest et al., 2013), using the lead author's role as a key organiser of the Conference, thereby gathering insights not only from the conference discussions, but the preparations including design, interactions with the advisory committee, and delivery of the conference. Due to the institutional affiliation of the authors, we can be considered grounded scholars and reflexive practitioners, both at the same time. In addition, we also bring insights from thematic discussions during the conference through the conference summary based on inputs from the leads of the different thematic discussions.

5.4 Results

Results are structured across four parts. In the first part, we present respondents' perspectives on the biggest issues facing the knowledge and innovation system, presenting results to an open-ended question on the topic. This is followed by results pertaining to the conference themes, where we not only present the priorities based on a ranking exercise but also further nuances within these priorities based on perspectives from the respondents as well as the conference summary. Thirdly, we present results on key factors that limit interaction among the different players within the system, which arise from an open-ended question on this issue. Finally, we set out the priorities for food systems transformation which emerge from the survey and conference discussions.

5.4.1 Biggest issues facing the food knowledge and innovation system

Based on our open-ended question to identify the biggest issues in the food knowledge and innovation system, the respondents proposed up to 3 of the biggest issues. A total of 629 issues were identified, which we coded into 10 categories, while six of these categories correspond to the six themes identified in Figure 5.1, the key additional themes identified include knowledge transfer, fragmentation in the innovation system and lack of systemic research, issues pertaining to food security, and 'other'. These additional themes are further considered in 4.10 as we seek to inductively identify priorities for food systems transformation. Figure 5.2 provides an overview of all themes, including the percentage of mentions.

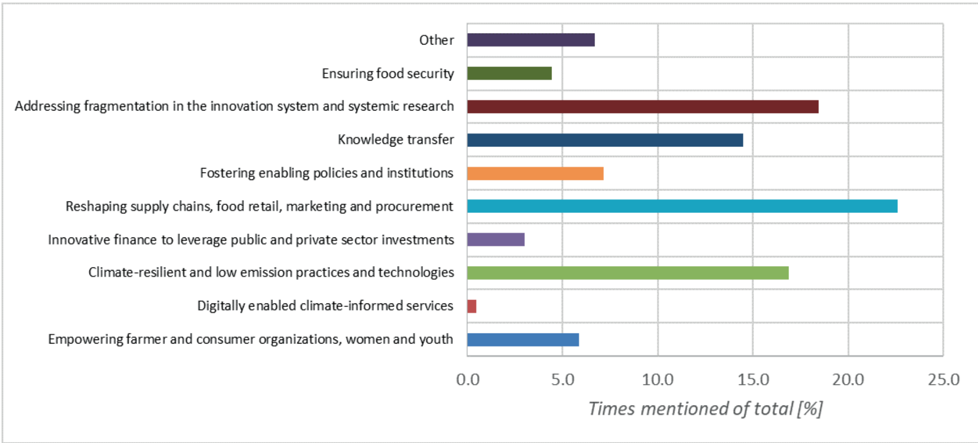


Figure 5.2 Inductively categorised priorities for the food knowledge and innovation system

5.4.2 Priorities across themes

Among the six themes that were proposed to respondents, the theme on 'Climate-resilient and low-emission practices and technologies' was identified by 34% of the respondents as the most important theme. This was followed by 'Empowering farmer and consumer organisations, women and youth' (23%), 'Fostering enabling policies and institutions' (15%), 'Reshaping supply chains, food retail, marketing and procurement' (11%), while 'Digitally enabled climate-informed services' and 'Innovative finance to leverage public and private sector investments' received 9% of the respondents' priority (as shown in Figure 5.3).

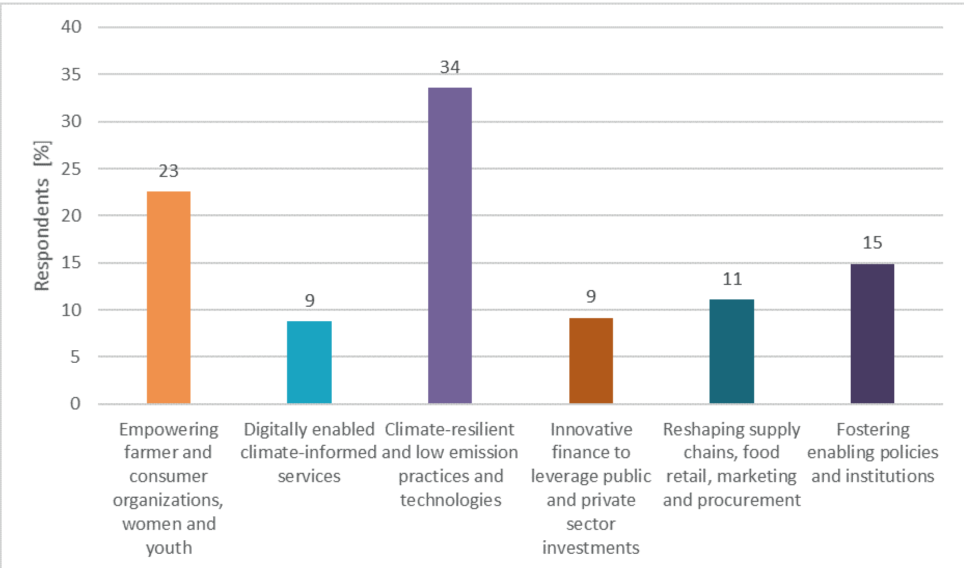


Figure 5.3 Most important themes to catalyse a transformation in food systems

5.4.3 Empowering farmer and consumer organisations, women and youth

23% of the conference participants ranked empowering farmer and consumer organisations, women and youth as the highest priority. We received 138 responses on key areas for research, and inductively we found the focus was on ensuring access to resources and technologies (33%), the inclusion of different stakeholder groups (24%), capacity building (21%), business and funding models (8%) and developing a suitable enabling environment (8%). We also received 115 responses on key areas for action, while the areas converge with those for research, the priorities varied, with the highest priority for capacity building (32%), followed by developing a suitable enabling environment (25%), ensuring access to resources and technologies (14%), inclusion of different stakeholder groups (12%), and business and funding models (10%).

Outcomes of thematic discussions around this theme at the conference (Dinesh, 2019) show that empowerment of farmers and consumer organisations, women and youth, requires an explicit focus on realising equitable outcomes, and stakeholders need to shift beyond business–asusual approaches, e.g. of collecting gender-disaggregated data, to an approach that addresses inequality explicitly, for example by ensuring women's access to technologies, services and information. The role of both formal and informal innovation platforms (Schut et al., 2019) that connect women farmers with men farmers and formal institutions and the private sector was also noted and is an area that requires more attention.

5.4.4 Digitally enabled climate-informed services

9% of the respondents indicated digitally-enabled climate-informed services to be the highest priority. Among the 51 responses received on key areas for research, we inductively identified focus to be on disruptive technologies and big data (35%) followed by generation of lessons from the application of digital tools (26%), the application of digitally enabled climate-informed services to extension (22%), and early response systems (14%). In terms of action, of the 44 responses received, the highest priority was accorded to the application of digitally enabled climate-informed services to extension (48%), followed by disruptive technologies and big data (23%), generation of lessons from the application of digital tools (21%), adaptive safety nets (5%), and early response systems (2%).

Thematic discussions at the conference highlighted evidence generation on both success and failure of digital agriculture initiatives by credible institutions and facilitation of knowledge sharing as key priorities in this theme (Dinesh, 2019). Knowledge sharing efforts can range from validation of claims around success of digital agriculture interventions, information sharing, and curation of complex scientific information, to address the diverse needs of stakeholders ranging from small to large farmers, private companies, Governments etc. Bundling of services, including climate, seed, fertiliser, credit, insurance etc., was identified as a preferred option for the private sector.

5.4.5 Climate-resilient and low-emission practices and technologies

34% of the respondents indicated climate-resilient and low-emission practices and technologies to be the highest priority. Among the 200 responses received on key areas of research, we inductively identified the focus to be on innovative scaling and capacity building (32%), generation of lessons from application (26%), context-specific support (15%), creating a suitable enabling environment for scaling (14%), and a focus on emerging innovations (10%). In terms of action, we received 174 responses, and the priorities differed. Respondents identified creating a suitable enabling environment for scaling as the most important area of action (36%), followed by innovative scaling and capacity building (34%), generation of lessons from application (13%), context-specific support (8%), and a focus on emerging innovations (4%).

Thematic discussions at the conference noted that technologies and practices need to be implemented as part of a suite of interventions, which address the challenges and barriers of uptake to fulfil their potential in terms of scale (Dinesh, 2019). It was also found there is a need for further awareness-raising and training of both farmers and consumers, policy support, knowledge on costs and benefits, and to align agendas so that promising interventions can be scaled rapidly.

5.4.6 Innovative finance to leverage public and private sector investments

9% of the respondents indicated innovative finance to leverage public and private investments to be the highest priority. From the 52 responses received on key areas for research, we inductively identified the focus to be on approaches to mobilise the finance needed for transformation in food systems (53%), establishing incentives for technology uptake (19%), improving monitoring, reporting and verification methods (14%) and mechanisms to de-risk private capital (8%). 43 responses were received on areas for action and show different priorities. Mobilising the finance needed for transformation in food systems remained the highest priority (51%), establishing incentives for technology uptake was the second priority (16%), followed by improving monitoring, reporting and verification methods (14%), and mechanisms to de-risk private capital (12%).

The conference summary noted that knowledge gaps limit the ability to evaluate the bankability and impacts of projects and need to be addressed to mobilise finance. Currently, knowledge is also fragmented at different scales, with uneven access. Improving accessibility and addressing fragmentation is an opportunity, particularly through digitalisation, which can also improve the measurement of impact, which is important to investors. In addition, behaviour change among farmers, measurement of co-benefits and incentives are other key priorities (Dinesh, 2019).

5.4.7 *Reshaping supply chains, food retail, marketing and procurement*

11% of the respondents indicated reshaping supply chains, food retail, marketing and procurement to be of the highest priority. From the 63 responses on key areas for research we inductively identified the focus to be on new models of business-to-business coordination (25%), new diets and consumer choices (19%), market regulations (19%), realising efficiency gains in the supply chain (18%) and efforts to reduce food loss and waste (6%). In terms of action areas, from the 56 responses, market regulations were identified as the highest priority (32%), followed by new models of business-to-business coordination (30%), new diets and consumer choices (18%), realising efficiency gains in the supply chain (5%) and efforts to reduce food loss and waste (2%).

While the conference endeavoured to take a food systems perspective, considering downstream activities in the system including retail, marketing and procurement, the focus of discussions were primarily on reducing food loss and waste (FLW) and changes to diets (Dinesh, 2019). There is a need to take a systemic perspective, and consider issues including behaviour change, trade, health, common definitions and systemic interventions.

5.4.8 *Fostering enabling policies and institutions*

15% of the respondents identified fostering enabling policies and institutions to be the highest priority. 90 responses were received on key areas for research, and we inductively identified the focus to be on governance issues and reforms to address inequities (38%), innovative approaches to policy design and implementation (31%), incentives for CSA (16%), and a focus on participatory approaches (12%). In terms of action, we received 84 responses, and governance issues and reforms to address inequities remained top priority (32%), followed by participatory approaches (31%), innovative approaches to policy design and implementation (19%), and incentives for CSA (16%).

During thematic discussions at the conference, it was found that policies and institutions need to transform from providing technical solutions to providing solutions that are relevant to specific farming circumstances, enabling farmers to improve their livelihoods (Dinesh, 2019). Top-down policy-making was identified as a concern and deterrent to the adoption of innovations. Knowledge systems need to tackle issues including the reforms needed to improve the livelihoods of farmers, livelihoods-based research at the farm level, more effective science-policy interfaces, and a systemic approach to issues.

5.4.9 *Factors that limit interaction among different players in the system*

We also identified the key factors that limit interaction among different players within the system. The key issue identified by respondents was around fragmentation of efforts (42%). These ranged from competition among institutions, a project-oriented approach etc. The other key factors included the culture of research and development (24%), equity within the knowledge system (22%), and the absence of long term thinking and implementation (10%).

Respondents noted several features in the culture of research and development including in communicating and disseminating research results, in partnering, and in doing outcome-oriented research as deterrents to improving interaction among players. It was also noted that the different players within the system are often unequal in terms of power relations, and this needs to be explicitly addressed for transformation. Efforts are also needed to foster long term thinking while designing research efforts, which also complement implementation efforts.

5.4.10 Priorities for food systems transformation

We hypothesised that to transform food systems under climate change, we need to catalyse research and action in the key areas set out in the framework (Figure 5.1), some of which pertain more to the food system, while others are more connected to the knowledge and innovation system, In practice, they are often coupled (Kok et al., 2019). Based on the survey responses, we now get further nuance on actions within these areas, as well as three additional inductively derived categories, namely: improving knowledge transfer, addressing fragmentation in knowledge and innovation systems, and addressing food security issues. Based on stakeholder perceptions we can identify not only the broad-based priorities but also more specific areas of focus for research and action (Table 5.1).

Table 5.1 Priorities for research and action under a new regime for innovation

Element of the theory of change	Priorities for research and action
Empowering farmer and consumer organisations, women and youth	- Inclusion of different stakeholder groups. - Ensuring access to resources and technologies. - Creating a suitable enabling environment for empowerment. - Building capacity to empower stakeholders. - Business and funding models to empower stakeholders.
Digitally enabled climate-informed services	- Generation of lessons from the application of digital tools. - Identifying and implementing disruptive technologies and big data approaches. - Provision of digitally enabled climate-informed services and extension. - Early response systems and adaptive safety nets.
Climate-resilient and low-emission practices and technologies	- Generate lessons from the application of technologies and practices. - Innovative approaches to achieving scale and building capacity. - Identifying and implementing emerging climate-resilient and low-emission innovations.

	- Provision of context-specific support for CSA. - Creating a suitable enabling environment for technology implementation.
Innovative finance to leverage public and private sector investments	- Approaches to mobilise finance for transformation. - Innovative financial mechanisms to de-risk private capital. - Identifying and providing incentives for technology uptake. - Improving approaches for monitoring, reporting and verification.
Reshaping supply chains, food retail, marketing and procurement	- Developing and implementing new models of business-to-business coordination. - Supporting new diets and consumer choices. - Efforts to manage food loss and waste. - Generating efficiency gains in the supply chain. - Market regulations to reshape supply chains, food retail, marketing and procurement.
Fostering enabling policies and institutions	- Innovative approaches to policy design and implementation. - Governance and reforms to address inequities in the food system. - Participatory approaches to policy design and implementation. - Incentives to scale CSA.
Knowledge transfer	- Improving approaches to dissemination and communication. - Enabling access to knowledge through user-oriented language, content, and products. - Translation of scientific knowledge to support implementation.
Fragmentation in the innovation system and lack of systemic research	- Improving approaches to partner with stakeholders. - Changing the culture within research and development. - Addressing fragmentation and duplication that stems from competition.
Ensuring food security	- Attention to poverty alleviation as part of a transformation. - Addressing nutritional needs and hidden hunger.

5.5 Discussion

5.5.1 Unpacking priorities for food systems transformation

There is a growing focus on proposals to transform food systems to achieve food security (Caron et al., 2018), which requires a food systems approach to research and action (Fanzo et al., 2020; Ingram, 2011; Reardon et al., 2019; Steiner et al., 2020). The priorities which have been validated, identified and elaborated in this chapter (Table 5.1) further confirm the importance of a food systems approach and provide elements for a theory of change to catalyse a transformation under climate change. Taking action along these priorities would require moving outside disciplinary silos, towards the common goal of achieving food security under a changing climate. The elements proposed in this theory of change can facilitate such transdisciplinary work based on key stakeholder-driven priorities. Within different priorities, sometimes the emphasis is more on food system change itself (e.g., how it is organised, the role of diets, the role of novel technologies), and sometimes the focus is more on how to organise for change (e.g., how to organise for knowledge exchange, mobilise finance).

On food system change itself, the theory of change prioritises the empowerment of farmer and consumer organisations, women and youth (Campbell et al., 2018) specifically around ensuring a strong voice for local organisations and stakeholders. Action and research in this area can build on earlier work on the role of civil society and grassroots organisations in transitions related to sustainability (El Bilali, 2019; Hermans et al., 2016), as well as on different adaptation and development pathways for different types of farmers (Stringer et al., 2020). These efforts are important in the context of the role of power and governance in transformations (Dentoni et al., 2017; Patterson et al., 2017).

Digitalisation has emerged as a key enabler for transformation in different sectors, economies, and businesses, and can enable food system change too. However, agriculture as a sector is behind others in the application of digital tools and services, which is a key opportunity for transformation (Klerkx and Rose, 2020; Shepherd et al., 2020), but challenges may be encountered especially in low-income countries where the scaling of digital tools is limited by the challenges faced by farmers (Bacco et al., 2019; Deichmann et al., 2016), capacity and investment gaps (Hinson et al., 2019). More research and action on the application of digital tools can help address these challenges and enable the transformation in food systems. In addition to digital tools, a wide array of technologies and practices are available which can accelerate such a transformation. These range from food production to diets and waste management (Herrero et al., 2020), and includes new and emerging technologies and practices which have transformative potential, such as artificial meat/fish, nano-drones, on-field robots, personalised food etc. (Herrero et al., 2020). Enabling adoption of such technologies and practices has transformative potential, but technological options need to be combined with social aspects (Barrett et al., 2020) and trade-offs and ethical concerns need to be addressed (Herrero et al., 2021; Klerkx and Rose, 2020). Experience from approaches like technology assessments and responsible research and innovation can help with this (Leeuwis et al., 2021; Rijswijk et al., 2021; Rose et al., 2016; Vanclay et al., 2013).

User-oriented research and action are needed across the food system, from farm to fork (Fanzo et al., 2020). This means a focus on actions beyond production, including supply chains, retail, marketing and procurement, diets, food loss and waste, and consumer choices (Loboguerrero et al., 2020; Vermeulen et al., 2020), which are key to food system change. Moving to healthy diets which enable us to remain within planetary boundaries (Willett et al., 2019) is a major area of opportunity, but requires deep structural changes in costing, policy, culture, equity and governance (Béné et al., 2020).

On organising for change, while Campbell et al. (2018) set out priorities for greater private sector activity, credit and insurance, the stakeholder-based priorities suggest further streamlining and developing new pathways for innovative finance to leverage public and private sector investments. Financial flows have been affected by market failures including lack of a deep pipeline of bankable projects, aggregation mechanisms and matchmaking facilities (Millan et al., 2019). These are important areas to address through research and action, developing innovative mechanisms, incentives and investment models that can enable overcoming these market failures. An example is blending public and private finance to reduce risk and mobilise capital rapidly, as in the case of the Global Innovation Lab for Climate Finance and the Agri Business Capital fund (Zougmoré et al., 2021).

Sustainability transitions are highly political (Avelino et al., 2016), and structures of power and vested interests create path-dependency and lock-in situations which make incumbent systems inert and difficult to change (Conti et al., 2021; Leeuwis et al., 2021). Therefore, the political economy has been highlighted as a key area of research for a food systems transformation (Béné et al., 2020; Leach et al., 2020; Turner et al., 2020). Enabling policies and institutions can be achieved through innovative approaches to policy design, implementation, land governance and reforms, trade rules etc. Such innovative approaches grounded in science, enable more effective science-policy interactions. However, a profound understanding of knowledge transfer in the context of transdisciplinary research is still largely missing (Adler et al., 2018). Appropriate processing of results to address user needs, supporting intermediaries and context-specific awareness have been highlighted as approaches to improve knowledge transfer (Nagy et al., 2020). Enhancing credibility, salience, and legitimacy of knowledge production has also been noted to increase the effectiveness of knowledge production (Cash et al., 2003; Opdam, 2010). Furthermore, efforts need to go beyond linear approaches, taking cognisance of institutional, power and participation dynamics (Cvitanovic et al., 2015; Leeuwis et al., 2021; van Kerkhoff and Lebel, 2006) and how researchers must deal with these dynamics (Lahsen and Turnhout, 2021). Fragmentation of knowledge and absence of systems thinking has been noted as a key problem for sustainability transitions (Kok et al., 2019; Saviano et al., 2019), therefore efforts are needed to address such fragmentation through long term thinking, systemic research, efforts to address disciplinary silos and more streamlined funding.

5.5.2 Actioning priorities for food systems transformation – Next Steps

Our findings provide a clear signal that stakeholders working at the interface of climate change, agriculture and food systems issues see the need for innovation and food systems transformation. Insights from the findings and the literature on innovation studies suggest that this would require efforts along three areas to implement the revised theory of change. These are:

(i) Stimulate novelty through niches

Novel approaches are needed within food systems, right from food production through to consumption. The priorities which have been identified (Table 5.1) provide areas to stimulate novelty through research and action. However, conscious efforts are needed to stimulate novelty in these areas to help catalyse a transformation in food systems aligned to the theory of change. To do this, knowledge and innovation systems need to change, and approaches such as strategic niche management (Kemp et al., 1998; Schot and Geels, 2008), wherein protected spaces are created to stimulate novel technologies or transition management where 'transition arenas' are created (Loorbach et al., 2017) are useful concepts. Strategic niche and transition management have a long tradition of application in agricultural transitions, including in the global South e.g. (El Bilali, 2020; Elzen et al., 2012; Hounkonnou et al., 2012), and could be extended to wider food systems (Leeuwis et al., 2021; Weber et al., 2020) and can inform underpinning knowledge and innovation systems (Meynard et al., 2017; Pigford et al., 2018). This would involve providing temporary protection or incentives for actions in the priority areas to stimulate novelty, which may come from different actors such as scientists, grassroots organisations, and start-ups, which challenge and contest current food system set-ups and propose (radical) alternatives (Herrero et al., 2020; Klerkx and Begemann, 2020; Leach et al., 2020). Such protection is needed to encourage investors and decision-makers to take risks to support such approaches which may often not be fully developed. These can include promoting the development and scaling of climate-resilient and low-emission practices and technologies, innovative financial mechanisms, approaches to scale digital solutions etc. Such extended application of strategic niche management can enable decision-makers to stimulate novelty across the priority areas.

(ii) Ensure participation in knowledge production

While stimulating novel approaches, it is essential for knowledge and innovation systems to be inclusive of stakeholders within food systems, including farmers, consumers, women and youth. Prior work (Brown et al., 2018; Kilelu et al., 2013; Leeuwis et al., 2021; Samian et al., 2016) has shown the crucial role of farmers in sustainability transitions, and in the face of climate change, it is anticipated that different types of farmers will need to follow different adaptation and development pathways (Stringer et al., 2020), and novel approaches need to be brought to farmers along these pathways. Novel approaches are also needed to bring capacity building and funding to enable farmers to take pathways that are climate resilient and generate lower emissions (Taneja et al., 2019). In addition to farmers, the role of consumers is also crucial (Vermeulen et al., 2020) while taking a food systems approach. To gain the trust of stakeholders, knowledge generated should be relevant to their needs, credible and legitimate (Cash et al., 2003), this means that structural changes are needed to the knowledge and innovation systems to ensure that these attributes are reflected in knowledge generated (den Boer et al., 2020; Kok et al., 2019). Good examples of ensuring participation can be seen in the growing emphasis on citizen science that bridges the gap between science and society and improves impact (Sauermann et al., 2020) and in science-policy engagement efforts (Dinesh et al., 2018), but efforts need to go beyond individual research projects or organisations to realise changes at the food system level (Turnhout et al., 2021).

(iii) **Reconfigure incumbent systems**

As noted in the introduction, the current knowledge and innovation system already faces several challenges including poor scaling logic and directionality, lack of understanding of the role of the private sector, misleading narratives, short term funding cycles, fragmentation, poor evidence base to support transformation, not sufficient focus on novel approaches and mission orientation (Hall and Dijkman, 2019; Klerkx and Begemann, 2020; Steiner et al., 2020). Therefore, a reconfiguration does not mean only addressing new areas (e.g. by stimulating niches), but also addressing structural issues in the current food system as well as knowledge and innovation system which may also be an effort including incumbent players (Conti et al., 2021; Turnheim and Sovacool, 2020). A food systems approach requires action from production through to consumption, and this implies both stimulating novelty but also phase-out of some activities across the system (Klerkx and Begemann, 2020; Leeuwis et al., 2021). To do this, knowledge and innovation systems that cover different parts of the food system need to be reconfigured to address the goals of transformation and integrated to stimulate novelty and organise phase-out across the system as opposed to only parts therein (Hall and Dijkman, 2019). While this is challenging, our results indicate that the community working across climate change, agriculture and food systems is cognisant of the need for change, which provides fertile ground for reconfiguration. This means that traditional disciplinary boundaries need to be surpassed so that innovation from the production end through to consumption are brought together. This will mean reconfiguring knowledge and innovation organisations to step up to this challenge. For example, the CGIAR is the international system for agricultural research, our findings point that organisations like the CGIAR need to move outside their comfort zones, which is in its legacy of crop breeding and the green revolution (Dinesh et al., 2021).

However, reconfiguring incumbent systems through disruptive innovation and phase-out will lead to winners and losers, as has been noted in the context of global change (O'Brien and Leichenko, 2003). Resistance may be encountered from the incumbent system (Conti et al., 2021; Smink et al., 2015), and this will need to be addressed (Herrero et al., 2020). It has been argued that through leadership and incentives (Dinesh et al., 2021), a reflexive approach (Sundbo and Fuglsang, 2006), and a mission-oriented approach to innovation (Klerkx and Begemann, 2020), it is possible to address such resistance. This would involve making contestation, negotiation and (productive) conflict more explicit part of the scope of innovation processes (Skrimizea et al., 2020; Turner et al., 2020). To track progress in this change process, not only is rigorous monitoring needed of how food systems transformation progresses in different dimensions of sustainability and thematic areas (Fanzo et al., 2021; Hebinck et al., 2021), but also of how the knowledge and innovation systems that support this transformation develop (den Boer et al., 2020; Klerkx and Begemann, 2020; Kok et al., 2019).

5.6 Conclusion

In 2020, the UN Secretary General, Antonio Guterres said, *"Our food systems are failing, and the COVID-19 pandemic is making things worse",* and he called for a transformation in food systems to make these systems more inclusive and sustainable (UN, 2020a). The Secretary General convened the first of its kind Food Systems Summit to take transformative action. This is not simple and comes with political challenges not only in preparations but also in delivering the ambitions through appropriate accountability mechanisms (Covic et al., 2021; Turnhout et al., 2021). In this context, building on the global initiative on 'Transforming Food Systems Under a Changing Climate', there is an opportunity to catalyse a transformation. However, a key knowledge gap remains around the 'How', i.e. how can a transformation be actioned and what does this mean for knowledge and innovation systems? We sought to address this knowledge gap by collecting and analysing insights of people working in the domain of AR4D, food systems, and climate change, thereby linking with the lived reality of practitioners.

In line with emerging experience in AR4D contexts (Douthwaite and Hoffecker, 2017; Maru et al., 2018; Thornton et al., 2017), AR4D practitioners are using ToCs to develop context-specific approaches to food systems transformation, and in this paper, we find that enacting a theory of change for food systems transformation under climate change can be an effective way to catalyse a transformation and we set out the key priorities for a theory of change. These priorities are placed within the broader perspective of knowledge and innovation systems, and we identify the next steps for better developing the new, reconfiguring the old and making knowledge generation more participative. For each of these three next steps, we can draw on valuable insights as developed in adjacent bodies of literature on innovation systems, system transition and transformation, and science-policy interactions.

CHAPTER 6

CONCLUSION

6.1 Conclusions and reflections

This dissertation set out to address two key knowledge gaps: Firstly, recognising that current efforts for science to inform policies for climate action in the food and agriculture sector are falling short, there is a need to identify how such efforts can be made more fruitful and deliver tangible outcomes and impacts for society. Secondly, as lessons drawn from the Global South and from the food and agriculture sector on improving science-policy engagement are limited, there is a need for further study on what works, what doesn't work, and how good practices can be mainstreamed. In order to address these gaps, I focused on a prominent effort for SPE in the food and agriculture sector in the Global South. Scrutinising efforts at multiple scales, I sought to expand the frontiers of current research on science-policy interactions with a focus on SPE that is more fruitful in delivering outcomes and positive impact.

I set out with the aim to generate systematic empirical insights regarding productive science-policy engagement in the domain of climate change, agriculture, and food security across different scales in the Global South. I studied the efforts of CCAFS in the context of the wider CGIAR network and the knowledge and innovation system for food and agriculture in the Global South. This dissertation makes contributions to several theoretical debates: Firstly, it expands the literature on science-policy interactions and interfaces, further specifying SPE as a distinct domain. This comes as a response to calls from scholars to elaborate engagement (Singh et al., 2019), as well as to bring practical insights and strategies concerning science-policy interactions (Gluckman et al., 2021; McNie, 2007). Throughout this dissertation, the concept of science-policy engagement has been defined as: *'the set of strategies and actions undertaken at the science-policy interface to achieve the goal of informing policy'*. This definition is complemented with examples of operationalising SPE at different scales, and lessons drawn from these experiences on how SPE can contribute to more productive cross-scale climate action in the agricultural and food sectors in the Global South.

This dissertation also sets out an agenda for future research and action for knowledge and innovation systems in developing more effective science-policy engagement and to drive a transformation in food systems in response to climate change. Future efforts to address these priorities will continue to enhance the contributions from this dissertation. Finally, the need for more interdisciplinary research in tackling pernicious problems has also been highlighted, and this dissertation draws on different disciplines to build the foundations of future SPE for climate action in the food and agriculture sector.

6.1.1 Factors for fruitful science-policy engagement

This dissertation sought to address the main research question: *"How can science-policy engagement contribute to more fruitful cross-scale climate action in the food and agriculture sector in the Global South?"* by answering the following related but subsidiary research questions –

SRQ1: What are the success factors for science-policy engagement for climate action and food security? (Chapter 2)

SRQ2: What are the fail factors and challenges for science-policy engagement for climate action and food security, and how can these be overcome? (Chapter 3)

SRQ3: How can effective science-policy engagement be institutionalised in the context of Agricultural Research for Development (AR4D) organisations? (Chapter 4)

SRQ4: What are the priorities for transformation in food systems and how can these be actioned in knowledge and innovation systems to enable effective science-policy engagement across the system? (Chapter 5)

The findings in Chapters 2 – 5 shed light on the SRQs; generating empirical insights from efforts to inform climate action at different scales in the food and agriculture sector regarding what works, what doesn't, how efforts can be institutionalised, and how efforts can be taken to scale across the entire food knowledge and innovation system – resulting in the theoretical contributions summarised in Table 6.1. Based on the conclusions around the subsidiary research questions, I now consider the main research question:

MRQ: How can science-policy engagement contribute to more fruitful cross-scale climate action in the food and agriculture sector in the Global South?

Based on the findings concerning the SRQs, it is evident that science-policy engagement is important at the levels of research projects, programmes, organisations, and knowledge and innovation systems for climate action in the food and agricultural sector in the Global South. To deliver the transformation needed in the sector in response to climate change, a focus on SPE as a distinct area holds merit. The chapters in this dissertation help lay the foundation for this by advancing the theory around SPE, as noted in Table 6.1.

Table 6.1 Theoretical contributions from science-policy engagement at multiple scales

Level	Theoretical contributions
Research project (ch. 2)	The three-thirds principle (wherein a third of the research effort is allocated to engagement, another third to evidence generation, and the final third to outreach, including communications and capacity building) is developed through successful SPE case studies and helping improve the efficacy of efforts at the level of research projects.
Research programme (ch. 3)	The approach to fail intelligently in SPE efforts through planning for failure, minimising risks in efforts, effective design of efforts, making failures visible, and learning from failures, can help improve SPE at the level of a research programme. Failures can be anticipated as a result of lack of salience in effort, lack of institutional capacity,

	adverse power dynamics, and funding uncertainties, and research programmes should plan for such failures.
Research organisation (ch. 4)	Efforts to institutionalise science-policy engagement can be done through: (1) increased accountability, (2) use of boundary objects, (3) participation across the boundary, (4) mediation and a selectively permeable boundary, (5) translation, (6) coordination and complementary expertise, (7) effective leadership, and (8) presence of incentives at the level of research organisations.
Knowledge and innovation system (ch. 5)	Priorities for knowledge and innovation systems derived from stakeholders can help orient SPE efforts towards systems change. These priorities include: (1) Empowering farmer and consumer organisations, women and youth; (2) Digitally enabled climate-informed services; (3) Climate-resilient and low-emission practices and technologies; (4) Innovative finance to leverage public and private sector investments; (5) Reshaping supply chains, food retail, marketing and procurement; (6) Fostering enabling policies and institutions; (7) Knowledge transfer; (8) Addressing fragmentation in the knowledge and innovation systems; and (9) Ensuring food security

Based on theoretical contributions across scales, certain overarching conclusions can be made. Firstly, the success conditions put forward by Cash et al. (2003) and which have provided the foundation for research on science-policy interfaces over the years can also be applied in the study of SPE, but the lens with which these conditions are studied needs to be different, with a focus on engagement. As seen in this dissertation, the focus on engagement dimensions provides novel and practical insights not yet captured in the literature and which can expand the theoretical foundations of SPE as a distinct area of SPI. Applying an engagement lens to the Cash et al. (2003) success conditions and related work can shed new light to strengthen and complement SPI research and action. This refers to the productivity of processes that are undertaken to enhance salience, credibility, and legitimacy, where the focus is on delivering favourable outcomes and impact. The engagement lens should not only be applied to successes and challenges overcome, but also to failures (as there is much to learn from failures), with the goal of improving approaches to failing as set out by the approach to failing intelligently.

Several examples of science-policy interfaces research focus on efforts at the level of projects and programmes; however, it is essential to consider institutionalising science-policy engagement within key knowledge organisations in the food and agriculture sector in order to achieve impact at scale. In this context, the CGIAR provides a case study that can also be applied to other organisations operating at the interface between science and policy. The institutional landscape in the food and agriculture sector is rather plentiful. At the global policy level, this includes the three United Nations agencies which focus on food and agriculture: the Food and Agriculture Organisation of the United Nations, the International Fund for Agricultural Development and the World Food Programme. At the regional level, there are several organisations that focus on policy and research. For example, at the African scale, the African Union takes a continental approach to policy, whereas the Forum for Agricultural Research in Africa focuses on agricultural research. Similarly, at the sub-regional level, there are dedicated institutions that complement each other on policy and research. An example is the Association for South-East Asian Nations (ASEAN), the secretariat of which focuses on driving policy and includes a working group on agricultural research for development with member states. This is complemented by research efforts through the Southeast Asian Regional Centre for Graduate Study and Research in Agriculture. At the national level, most countries have dedicated National Agricultural Research institutions or systems that work closely with relevant government Ministries. Despite such a rich landscape of institutions working on policy and research across different scales, the potential of SPE to achieve climate change outcomes is under-utilised. It was found that only 7% of the investments in agricultural innovation in the Global South focused on objectives related to climate change and the environment (CoSAI, 2021). Across these institutions, there exists the potential to apply lessons to better implement SPE and expand on the delivery of outcomes for climate change. However, it must be noted that institutional design comes with challenges, including shifting the focus of incumbent organisations and systems. Efforts to create new mechanisms for SPIs have been critiqued (Turnhout et al., 2021); indeed, the food and agriculture sector is the one where a UN institution (World Food Council) was created and then wound up (Shaw, 2010). This clearly indicates that institutional reform is a challenging endeavour.

Reforming existing and creating new organisations are a key aspect of the response to climate change and food security issues, and future organisations should embrace SPE as a powerful tool that can help enrich decision-making processes. This requires strategically embedding SPE within organisation-wide efforts, creating a culture to learn from past successes and failures, implementing good practice on institutionalising SPE, and addressing novel research and action priorities for maximum impact.

An agenda for science-policy engagement needs to complement a new research and action agenda in food systems, one that purposefully aims to catalyse a transformation. Applying SPE to such research and action can help deliver the transformation needed. This approach should transcend disciplinary boundaries, as seen in this dissertation. The application of other disciplines, notably failure management, institutional design, and innovation science, can further help shape research and action in this area. For example, the literature on failure management has been widely applied in other sectors and enables stakeholders to improve the efficacy of efforts. Applying these lessons to SPE in the food and agriculture sector has the potential to similarly improve future endeavours, as noted in Chapter 3. Such an application helps foster more experimentation and trial-and-error, and moves away from a culture where only success or the promise thereof is rewarded. Similarly, in the context of the present institutional landscape for agricultural research for development and the flows of funding for these activities, very little effort has been made to institutionalise SPE to foster climate action. Applying lessons generated from past experience can help these organisations to be more effective in fostering science-based policies and practices. Finally, linking growing calls for the transformation of knowledge and innovation systems to transforming incumbent regimes for research and innovation has the potential to catalyse systemic change, one that benefits both climate and society at scale.

6.1.2 Lessons to make science-policy engagement work across scales

Applying different disciplines and studying the quality of science-policy engagement at multiple scales demonstrates that for fruitful SPE across the knowledge and innovation system such efforts must occur in a coordinated manner. Table 6.2 provides insight on increasing efficiencies across the different scales studied.

Table 6.2 Key insights on SPE working across scales

	What is needed from?			
	Project	**Programme**	**Organisation**	**System**
Project		The programme needs to be open to experimentation, willing to embrace failures, and not only reward success or the promise thereof.	The organisation needs to be mission-oriented and provide the trust and space for projects to take risks and grow to deliver the mission. In this process, the organisation needs to be open to failures and provide incentives to innovate.	The system needs to stimulate novelty and should be willing to fund projects that promote new ideas and cultivate a critical perspective. The system should also foster communities of practice and knowledge networks for greater collaboration.
Programme	Projects need to have effective SPE strategies and leadership in place, and not take these to be granted.		The organisation needs to provide programmes with true space to experiment and fail and incentivise SPE efforts to achieve its mission.	The system needs to provide programmes with more coherent Theories of Change to deliver a transformation in food systems, and ways to share and spread knowledge easily.
Organisation	Projects need to provide organisations clear and transparent	Programmes should be seeds for change for the organisation, pioneer mission		The system needs to help reshape organisations to deliver coherent theories of change and provide

	narratives, careful documentation and good examples.	orientation, take risks, and have strategies to fail intelligently.		incentives to collaborate with each other.
System	Projects need to engage directly with the system, stepping outside silos and engaging with the wider knowledge and innovation system for impact.	Programmes should become strategic niches of innovation and use knowledge across the system and drive a transformation. This involves taking risks and being open to failure.	Organisations need to be mission-oriented and focus on priorities for systems transformation. Such a transformation needs to be based on collaboration with other organisations, while remaining clear about own positionality.	

The three-thirds principle provides a way of designing projects which foster productive SPE. However, project-level efforts need to be complemented by programme-level efforts, where research managers are open to failure and experimentation. Efforts are also needed within an organisational context to be mission-oriented, with science-policy engagement efforts within projects incentivised to deliver the mission. Furthermore, project novelty and risk-taking should be encouraged and designed to cultivate a critical perspective.

Having a portfolio of projects which are designed for SPE is essential for successful research programmes. These projects need to have leadership in place to implement SPE strategies and deliver favourable outcomes and impact. These initiatives should be complemented at the organisational level, providing true space to experiment and fail, and offering incentives to deliver on objectives. Programmes also require the knowledge and innovation systems to provide coherent theories of change and support to share and spread knowledge effectively.

For research organisations, projects need to provide clear and transparent narratives, careful documentation, and good examples. This is closely linked to the need for programmes to be seeds of change, unafraid of taking risks and failing intelligently, with a portfolio of well-designed and executed projects. The knowledge and innovation system should also reshape organisations as needed to deliver coherent theories of change, alongside providing incentives to collaborate.

Knowledge and innovation system reform is crucial for successful science-policy engagement, and the current focus on climate change issues in the agricultural knowledge and innovation system remains below par. For this to change, projects should actively engage with the system, break silos, and work towards achieving greater impact. Programmes should become strategic niches of innovation and lead the way for a transformation in the system, taking risks and embracing failure along the way. Research organisations need to be mission-oriented, and this may ultimately involve re-imagining their core purpose to fulfil theories of change across the system.

6.1.3 Implications for science-policy engagement research

While it is clear that actions at different levels are important and interlinked, how can these efforts be put to work in a cohesive way? This dissertation uses the Cash et al. (2003) success conditions as a key foundation, exploring their relationship with success, failure, and institutionalisation. I used these principles to determine how efforts at different scales can be operationalised to deliver SPE across different scales (Table 6.3).

Table 6.3 Conditions to enhance salience, credibility and legitimacy across scales

	Project	**Programme**	**Organisation**	**Knowledge and Innovation system**
Salience	Engage with users more effectively and produce salient knowledge.	Recognise that lack of salience can lead to efforts to fail and plan accordingly.	Use boundary objects, be accountable to the next users, mediate and translate to ensure salience.	Achieve salience through a focus on stakeholder-driven priories for research and action.
Credibility	Generate credible evidence.	Take efforts to develop and maintain scientific credibility even in novel efforts.	Ensure mechanisms for mediation to balance trade-offs that may arise.	Produce credible knowledge in priority areas to enable a transformation.
Legitimacy	Prioritise participatory approaches to gain legitimacy.	Develop trust of internal and external stakeholders by creating an environment that is open to failing.	Ensure accountability to stakeholders by providing incentives to staff and by providing leadership.	Engage stakeholders to ensure legitimacy.

Establishing a fruitful relationship between science and policy is no easy task. Effort must be made to interlink actions across different scales. This dissertation has made evident that efforts at the programme and project levels are interlinked and mutually supportive, which helps to advance science-policy engagement. When looking at the scale of an organisation, and where the organisation itself is going through a reform process, it is evident that this comes with multiple challenges, and efforts are not always successfully interlinked. Nonetheless, with committed leadership and incentives this is possible. At the same time, within the knowledge and innovation system as a whole, the effectiveness of SPE needs to be more systematically addressed. These interlinkages can be studied and improved upon, but power imbalances are also evident. An effective SPE-focused project or programme has very little influence on the overall knowledge and innovation system, which may be entrenched in its ways and fragmented. An effective knowledge and innovation system can greatly benefit the design of projects and programmes that use SPE to deliver favourable outcomes and impact. Although researchers can be agents for change, like knowledge brokers, reflexive scientists, and process facilitators, their impact is far from optimal (Wittmayer and Schäpke, 2014).

This dissertation highlights areas of science-policy engagement which have not yet been studied as a distinct area of science-policy interfaces. Based on the findings of this dissertation, it is clear that there is scope to study this area as a distinct part of the scholarly work on SPI. This dissertation also establishes the foundation for further study based on success factors, fail factors, lessons for institutionalisation, and priorities for knowledge and innovation systems. It should be noted, however, that the single embedded case study on the CGIAR is primarily focused on informing decision-makers (Clark et al., 2016a). While this involves some political challenges, these efforts are largely based on rational and technical considerations. The political aspects of the CGIAR case study have yet to receive attention, which will emerge in the context of negotiations and enlightenment in science-policy interactions (Clark et al., 2016a).

These insights are relevant to climate action in food systems. The role of science for policy was identified as a priority almost four decades ago (Agrawala, 1999), but practitioner and scholastic efforts have not yet managed to reverse accelerating human-induced climate change. Improving the overall approach through a focus on SPE can strengthen these efforts. This is especially true in the food and agriculture sector, where discussions focus on strengthening the science-policy interface. However, scholars have noted that this is not only about creating new mechanisms but about strengthening the emphasis on engagement and action (Turnhout et al., 2021). This dissertation contributes to the theoretical foundations and debate on science-policy interactions with regards to both the climate action and the food and agriculture sector, thereby serving as a bridge between two important communities whose concerted efforts are needed for a transformation in food systems. SPE can be an important tool that enables action at the level of projects, programmes, organisations, and the knowledge and innovation system. To catalyse SPE efforts across these scales, the *status quo* which currently exists needs to be broken down. This requires leadership with the willingness to take charge and take risks. Indeed, this is the reason I propose to establish a new 'Think and Do Tank' for food and climate, unleashing the potential that SPE has to offer.

6.2 Contributions to CCAFS and beyond

This dissertation has helped CCAFS critically examine its work in the sphere of science-policy engagement and subsequently learn from these efforts. It assisted in linking SPE efforts within CCAFS with research advances on the topic. The most recent evaluation of

CCAFS (Nelson and Morton, 2020) positively reviewed its SPE efforts, and this dissertation has played a critical role in grounding CCAFS with research on the subject. Although CCAFS closes in 2021, the lessons generated remain relevant to the wider CGIAR, as demonstrated in Chapter 4. This is particularly true because there has been a growing emphasis on SPI in the food and agriculture sector (Hainzelin et al., 2021). The CGIAR is currently in the process of developing a portfolio of new initiatives, and findings from this dissertation can help enhance the impact of this work.

In CCAFS, the CGIAR, and the wider knowledge and innovation system for food and agriculture, research and practice on SPE have been moving at different paces. The priority should be to reconcile the disconnect between research and practice, wherein research on SPE informs practice and vice versa. In this context, some key recommendations emerge for practice:

Firstly, mechanisms for interfacing science with policy in food and agriculture are highly fragmented (Roodhof et al., 2021) and it is evident that ‘business as usual’ approaches are not sufficient to drive the transformation that is needed. The explicit focus that stakeholders within the knowledge and innovation systems put on knowledge transfer and production issues, as observed in Chapter 5, makes this evident. This means that new and innovative approaches are needed at the interface between science and policy, with a greater focus on providing practical guidance. Engagement can play an important role here, providing this guidance across scales. There are different mechanisms to bridge this gap between research and practice: scientists taking on coordination roles (Macleod et al., 2008), knowledge brokering (Gluckman et al., 2021), intergovernmental assessments (Maas et al., 2021), or, as in the case of this dissertation, an approach to reflexivity among practitioners. There is no one-size-fits-all, and mechanisms should be chosen based on the particular context.

Throughout this research, I have noticed a growing shift within the agriculture and food sector to look at food systems as a whole. This means a focus beyond production issues to also include distribution, consumption, and food waste. In this context, mechanisms for science-policy interfaces which have a systems perspective would be useful and are currently lacking. Most mechanisms in the sector are focused on parts of the system. Taking a holistic systems approach requires moving out of disciplinary boundaries, setting up new and revisiting old mechanisms for interactions. Although proposals for establishing an IPCC for Food have been critiqued (Clapp et al., 2021; Turnhout et al., 2021), we do need to rethink how science-policy interactions can be more effective across the whole food system.

6.3 Directions for SPE practitioners and researchers

While I have drawn conclusions at the level of projects, programmes, organisations, and the knowledge and innovation system, I would like to also offer reflections on the changing role of science-policy engagement practitioners and researchers. I started in my role with CCAFS as Global Policy Engagement Manager in 2014, tasked to work at the interface of science and policy to deliver greater impact and outcomes from the research across the programme. I worked in this area with no prior training or knowledge of the research on science-policy interactions. In 2017, I became a researcher, and thus a reflexive practitioner, viewing my work more critically based on the advances in the literature. In this capacity, I was able to appreciate and critique CCAFS' efforts at science-policy engagement, which I would otherwise not have been able to do.

A key aspect to CCAFS' success with science-policy engagement was an environment characterised by an entrepreneurial approach, wherein it was possible to identify and engage in emerging policy opportunities. Such an entrepreneurial approach enables researchers and practitioners who are committed to driving change in society to realise favourable outcomes and impact. The approach taken by CCAFS' researchers and practitioners is similar to the concepts of evangelism which have emerged in the literature on marketing (Kawasaki, 2010).

However, while studying the wider organisation, as well as the knowledge and innovation system, I did not find a similar entrepreneurial approach regarding the empowerment of researchers and practitioners on science-policy engagement. I consider this an important reason why science-policy interfaces are sub-optimal; it is not due to a lack of commitment from researchers and practitioners, but a general disempowerment within the wider organisational and knowledge and innovation systems. Unless these issues are addressed to enable practitioners and researchers, efforts will remain sub-optimal. Scholars have called for greater institutional reflexivity (Salmon et al., 2017; Wynne, 1993) and noted the role of politics in defining institutional mandates. The same is the case with the CGIAR. Various rounds of reforms over the past two decades have reflected political struggles between the constituent centres and funders. Recently, with increasing pressure from funders, including private philanthropists (Herdt, 2012; IPES-FOOD, 2020), criticisms regarding the change in CGIAR priorities, issues of democracy, power imbalances, and areas of focus are being voiced by experts (IPES-FOOD, 2020). Amidst this struggle, there is a risk that the capacities of the CGIAR and the potential of its scientists will be under-utilised.

The critical and reflexive approach I adopted in viewing SPE efforts across scales led me to view the aforementioned changes as having the potential to disempower me in making a difference for climate and society. As a result, I decided to leave the CGIAR system once CCAFS ends in 2021. I feel that my actions will be limited by the wider organisation and the knowledge and innovation system.

While a great deal has been written on the role of farmers and consumers as agents of change within the food system, this also needs to extend to the role of researchers and practitioners of science-policy engagement. As has been noted in the context of sustainability transitions, researchers can be agents for change, knowledge brokers, reflexive scientists, and process facilitators (Wittmayer and Schäpke, 2014). The expectations on researchers are changing in the context of SPE; researchers are no longer expected to just deliver sound research publications, but to contribute to societal impact and outcomes. This requires a different skill set from what researchers may currently possess. As an SPE practitioner, I gained skills in research through this dissertation. Researchers need to do the opposite, and gain skills in SPE.

Einstein famously said, *"We cannot solve our problems with the same thinking that created them"*. This can be applied to science-policy engagement, where the same thinking that has led us to a broken food system (Schmidt-Traub et al., 2019) and the climate crisis will not help turn the tide. We need radically different approaches which empower the SPE practitioner and researchers. Breakthrough concepts such as innovation evangelism in marketing (Kawasaki, 2010), and mission orientation (Mazzucato, 2021) need to be applied. This responsibility cannot lie purely with researchers, as research organisations and funders need to foster an environment that enables radically different and innovative thinking.

This does not exclude practitioners and researchers from their responsibilities. Even when the system does not provide a conducive environment, we have a moral obligation to act. In my experience, the way to do this is to identify others as part of a network with similar values and objectives, which can then help advance transformative action. Influential individuals need to step up, and where this is not possible, step out of the system or start playing a different role in the system if they believe that this is needed.

6.4 Reflections on methods and recommendations for further research

This dissertation employs several different methods for the different chapters; including surveys with CCAFS project leaders (Chapters 2, 3), a sample of the knowledge and innovation system (Chapter 5), key informant interviews with research leaders (Chapter 2), managers (Chapter 3) and important stakeholders in the CGIAR response to climate change (Chapter 4). Programme documents as well as grey and peer-reviewed literature are also reviewed. In addition, participant observation is used as a method in Chapter 5, and development and analysis of case studies on SPE in Chapters 2 and 3. The diversity of methods used helps gather different kinds of insights across the scales of study, despite bringing challenges regarding securing responses and inputs around failures. Despite these challenges, I was able to generate fresh, reliable, and valid insights which also serve to open up further areas of research.

While there is some recognition in the literature regarding the importance of engagement (Ramirez and Belcher, 2020; Singh et al., 2019), there hasn't been sufficient research and practical guidance on the topic. Through the chapters of this dissertation, the role and importance of science-policy engagement as a distinct part of the literature on science-policy interfaces becomes evident. Building upon this calls scholars to unpack engagement in SPI, working to highlight critical issues for SPE in the wider context of SPIs, drawing on theories of failure management, institutional analysis and design, and innovation science. This helps to generate new insights on effective SPE, which can help the overall objective of SPIs to enrich decision-making. These efforts have led to new research questions and topics, for which the key recommendations for further research are summarised as follows:

Firstly, further research on science-policy engagement as a sub-domain of science-policy interfaces is essential, not only to identify key features, but to enable practitioners to engage at the interface of science and policy more effectively. Research efforts must shed light on practical aspects of SPE, including how decisions are made and relationships maintained, which has been stressed in earlier work (McNie, 2007). As a practitioner, the focus of my work is very much on engaging at the SPI, so research on what works, how, and where, can help me and other practitioners in our goal of connecting science to policy. An explicit focus on SPE which is distinct from SPI and boundary work can be useful to produce novel insights relevant to practitioners and scholars.

Secondly, I found that failures and challenges are not receiving sufficient focus in science-policy interface research. To improve science-policy interactions it is crucial to learn from failures, and a key area of further research is to study failed efforts so that the efficacy of future SPE endeavours can be improved. The concept of science for policy was introduced over four decades ago (Agrawala, 1999), but efforts are still proving insufficient for the scale of action needed. To improve efforts, we need to know who has failed, why, when, and in what circumstances – to fail intelligently at the SPI. While this dissertation identifies fail factors from the CCAFS, future research can shed light on similar factors in other contexts and identify additional factors. In addition, this dissertation has not considered end-user perspectives on failure, which would be a useful additional research topic. Despite all this, it must be noted that studying failure is extremely challenging in a culture which does not embrace failure.

There is also a need for more research on creating organisations that can effectively design and implement effective science-policy engagement strategies. This should build on earlier work on designing organisations that work more effectively at the interface between science and policy, including through boundary spanning and brokerage functions (Bednarek et al., 2018; Gluckman et al., 2021; Sarkki et al., 2019). Through this dissertation, I have sought to address this need in the context of the food and agriculture sector. However, further research focused on other organisations in the sector is needed to deliver a set of ‘fit for purpose’ organisations that enable SPE. For example, the International Fund for Agricultural Development (IFAD) has a focus on policy engagement (Phillips, 2017) and guides its staff to engage in the policy process. There exists an opportunity to tap into this interest, as IFAD is also a major investor in agricultural research. Further research should also focus on some of the key barriers that may be faced in reform efforts, including the prevailing culture and 'science politics', which have been identified in Chapter 4.

Finally, reconciling the supply and demand of knowledge is a key theme that has already been identified (Sarewitz and Pielke, 2007). However, from a practitioner's perspective, actionable, demand-driven research is still insufficient. Current approaches to boundary spanning can often be disconnected from the knowledge production process and not be sufficiently interdisciplinary. Therefore, an approach that is integrated with the knowledge generation process and is truly interdisciplinary was found more effective in this dissertation. Further empirical case studies that harvest insights on reconciling supply and demand through an integrated approach could bring value to research and practice.

6.5 Science-policy engagement for climate action in agriculture and food: final observations

As an addendum to the conclusions this dissertation, I would like to provide some final observations. As a reflexive practitioner working at the interface between science and policy, I was able to reflect critically on my work using the literature on the interface between science and policy as well as the theories on failure management, institutional analysis and design, and innovation science. In this journey, I observed two major disconnects:

The first was between science and practice. The practice of science-policy engagement was not sufficiently rooted in the *science* of science-policy interactions. Both areas have advanced, but in different directions. It was only through forming this dissertation that my own practice became adequately grounded in science. The reasons for this disconnect are several, the foremost being that there hasn't been much research on the practical aspects as previously identified (McNie, 2007). While scholarly work on SPI has advanced, theoretical advances need to connect with practitioners more effectively. There is a risk that the 'science' in SPI becomes a silo in itself, not connecting effectively to decision-making processes.

The second disconnect I encountered exists between the current state of efforts (both research and practice) and what is needed. The magnitude of the climate change challenge in the food and agriculture sector is immense. Global food security is under threat as climate change impacts are accelerating and food systems are second only to energy as the biggest drivers of climate change. This considered, a transformation in food systems is needed urgently (Loboguerrero et al., 2020). Current approaches to inform policy remain insufficient and fragmented, and SPE efforts need to innovate to catalyse transformative action. Clark et al. (2016) call for enlightened spaces for science-policy work, where there exists a seamless interface between research and practice (Clark et al., 2016a) – but this is absent in my area of work, working at the interface between science and policy in the food and agriculture sector's response to climate change. Organisations that are responsible for SPE are rooted in the legacy of the past and are not fit to catalyse the transformation that is urgently needed.

The only way to address these disconnects is to radically change our approach to research, practice, and organisations for SPE. The research agenda in food and agriculture needs to be more aligned towards transformation, and must enable practitioners to effectively implement these ideas. The action agenda also needs to move from incremental to transformative, implementing novel ideas and approaches from transformative research. Finally, organisations for SPE need to be radically reformed, phased out, or created to catalyse the transformation needed. As the famous quote goes, *"The definition of insanity is doing the same thing over and over again and expecting different results"*. To get the transformative results urgently needed, we must experiment with different ingredients in our food system.

As a result of these observations, I propose to develop a 'think and do tank' for food and climate. Think and do tanks differ from conventional think tanks in that, in addition to policy-oriented research and analysis, they engage in advocacy and technical assistance (Stone, 2001). This new endeavour will seek to bring about the transformation in terms of process and content, bringing new and innovative ideas to the table and getting these actioned through SPE efforts. One of the most compelling quotes I encountered in my interviews was noted in chapter 4: *"culture eats strategy for breakfast"*. This implies that unless the advances in theories and strategies are backed by a change in culture, SPE efforts will not get to the level necessary to transform food systems under the pressure of accelerating climate change. Through the proposed 'think and do tank', I will seek to change the culture around science and policy for accelerated climate action in food systems.

ENDNOTES

REFERENCES

APPENDICES

ACKNOWLEDGEMENTS

ABOUT THE AUTHOR

References

Abson, D.J., Fischer, J., Leventon, J., Newig, J., Schomerus, T., Vilsmaier, U., von Wehrden, H., Abernethy, P., Ives, C.D., Jager, N.W., Lang, D.J. (2017) Leverage points for sustainability transformation. Ambio 46, 30-39.

Adler, C., Hirsch Hadorn, G., Breu, T., Wiesmann, U., Pohl, C. (2018) Conceptualizing the transfer of knowledge across cases in transdisciplinary research. Sustainability Science 13, 179-190.

Agrawala, S. (1999) Early science–policy interactions in climate change: lessons from the Advisory Group on Greenhouse Gases. Global Environmental Change 9, 157-169.

Alexandratos, N., Bruinsma, J., (2012) World agriculture towards 2030/2050: the 2012 revision. Food and Agriculture Organisation of the United Nations, Rome, Italy.

Alston, J.M., Pardey, P.G., Rao, X., (2020a) The Payoff to Investing in CGIAR Research. SoAR Foundation, Washington DC.

Alston, J.M., Pardey, P.G., Rao, X., (2020b) The Payoff to Investing in CGIAR Research. SoAR Foundation, Washington, DC.

Anderson, S., Khan, F., Robledo, C., Roth, C., (2016) Evaluation of the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Independent Evaluation Arrangement (IEA) of the CGIAR, Rome, Italy.

Anderson, S., Sriram, V. (2019) Moving Beyond Sisyphus in Agriculture R&D to Be Climate Smart and Not Gender Blind. Frontiers in Sustainable Food Systems 3.

Armitage, D., de Loë, R.C., Morris, M., Edwards, T.W.D., Gerlak, A.K., Hall, R.I., Huitema, D., Ison, R., Livingstone, D., MacDonald, G., Mirumachi, N., Plummer, R., Wolfe, B.B. (2015) Science–policy processes for transboundary water governance. Ambio 44, 353-366.

Arnott, J.C., Neuenfeldt, R.J., Lemos, M.C. (2020) Co-producing science for sustainability: Can funding change knowledge use? Global Environmental Change 60, 101979.

Aryal, J.P., Mehrotra, M.B., Jat, M.L., Sidhu, H.S. (2015) Impacts of laser land leveling in rice–wheat systems of the north–western indo-gangetic plains of India. Food Security 7, 725-738.

Ash, A., (2013) Managing the CCAFS Theme by Region matrix for international public goods and development outcomes. CGIAR Research Program on Climate Change, Agriculture and Food Security Independent Science Panel, Copenhagen, Denmark.

Augustin, M.A., Cole, M.B., Ferguson, D., Hazell, N.J.G., Morle, P. (2021) Perspective article: Towards a new venture science model for transforming food systems. Global Food Security 28, 100481.

Avelino, F., Grin, J., Pel, B., Jhagroe, S. (2016) The politics of sustainability transitions. Journal of Environmental Policy & Planning 18, 557-567.

Bacco, M., Barsocchi, P., Ferro, E., Gotta, A., Ruggeri, M. (2019) The Digitisation of Agriculture: a Survey of Research Activities on Smart Farming. Array 3-4, 100009.

Barrett, C.B., Benton, T.G., Cooper, K.A., Fanzo, J., Gandhi, R., Herrero, M., James, S., Kahn, M., Mason-D'Croz, D., Mathys, A., Nelson, R.J., Shen, J., Thornton, P., Bageant, E., Fan, S., Mude, A.G., Sibanda, L.M., Wood, S. (2020) Bundling innovations to transform agri-food systems. Nature Sustainability 3, 974-976.

Baruch, Y., Holtom, B.C. (2008) Survey response rate levels and trends in organisational research. Human Relations 61, 1139-1160.

Baumard, P., Starbuck, W.H. (2005) Learning from failures: Why it May Not Happen. Long Range Planning 38, 281-298.

Beddington, J., Adesina, A., Evans, W., Harch, B., Karuku, J., Lohani, B., Shapiro, H.-Y., Sithole-Niang, I., Vieira Teixaira, I.M., (2014) Final Report from the Mid-Term Review Panel of the CGIAR Reform. CGIAR Consortium, Montpellier, France.

Bednarek, A.T., Wyborn, C., Cvitanovic, C., Meyer, R., Colvin, R.M., Addison, P.F.E., Close, S.L., Curran, K., Farooque, M., Goldman, E., Hart, D., Mannix, H., McGreavy, B., Parris, A., Posner, S., Robinson, C., Ryan, M., Leith, P. (2018) Boundary spanning at the science–policy interface: the practitioners' perspectives. Sustainability Science 13, 1175-1183.

Belcher, B.M., Rasmussen, K.E., Kemshaw, M.R., Zornes, D.A. (2015) Defining and assessing research quality in a transdisciplinary context. Research Evaluation 25, 1-17.

Béné, C., Fanzo, J., Haddad, L., Hawkes, C., Caron, P., Vermeulen, S., Herrero, M., Oosterveer, P. (2020) Five priorities to operationalize the EAT–Lancet Commission report. Nature Food 1, 457-459.

Biagini, B., Kuhl, L., Gallagher, K.S., Ortiz, C. (2014) Technology transfer for adaptation. Nature Climate Change 4, 828.

Bielak, A.T., Campbell, A., Pope, S., Schaefer, K., Shaxson, L., (2008) From Science Communication to Knowledge Brokering: the Shift from 'Science Push' to 'Policy Pull', in: Cheng, D., Claessens, M., Gascoigne, T., Metcalfe, J., Schiele, B., Shi, S. (Eds.), Communicating Science in Social Contexts: New models, new practices. Springer Netherlands, Dordrecht, pp. 201-226.

Biermann, F. (2007) 'Earth system governance' as a crosscutting theme of global change research. Global Environmental Change 17, 326-337.

Birner, R., Byerlee, D., (2016) Synthesis and lessons learned from 15 CRP evaluations. Independent Evaluation Arrangement (IEA) for the CGIAR, Rome, Italy.

Bromley-Trujillo, R., Karch, A. Salience, Scientific Uncertainty, and the Agenda-Setting Power of Science. Policy Studies Journal n/a.

Brown, B., Nuberg, I., Llewellyn, R. (2018) Further participatory adaptation is required for community leaders to champion conservation agriculture in Africa. International Journal of Agricultural Sustainability 16, 286-296.

Byerlee, D., Lynam, J.K. (2020) The development of the international center model for agricultural research: A prehistory of the CGIAR. World Development 135, 105080.

Cáceres, D.M., Silvetti, F., Díaz, S. (2016) The rocky path from policy-relevant science to policy implementation—a case study from the South American Chaco. Current Opinion in Environmental Sustainability 19, 57-66.

Campbell, B., Hansen, J., Rioux, J., Stirling, C.M., Twomlow, S., Wollenberg, E. (2018) Urgent action to combat climate change and its impacts (SDG 13): transforming agriculture and food systems. Current Opinion in Environmental Sustainability 34, 13-20.

Campbell, B.M., Beare, D.J., Bennett, E.M., Hall-Spencer, J.M., Ingram, J.S.I., Jaramillo, F., Ortiz, R., Ramankutty, N., Sayer, J.A., Shindell, D. (2017) Agriculture production as a major driver of the Earth system exceeding planetary boundaries. Ecology and Society 22.

Campbell, B.M., Thornton, P.K., (2014) How many farmers in 2030 and how many will adopt climate resilient innovations? CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Copenhagen, Denmark.

Campbell, B.M., Vermeulen, S.J., Aggarwal, P.K., Corner-Dolloff, C., Girvetz, E., Loboguerrero, A.M., Ramirez-Villegas, J., Rosenstock, T., Sebastian, L., Thornton, P.K., Wollenberg, E. (2016) Reducing risks to food security from climate change. Global Food Security 11, 34-43.

Cannon, M.D., Edmondson, A.C. (2001) Confronting failure: antecedents and consequences of shared beliefs about failure in organisational work groups. Journal of Organisational Behavior 22, 161-177.

Cannon, M.D., Edmondson, A.C. (2005) Failing to Learn and Learning to Fail (Intelligently): How Great Organisations Put Failure to Work to Innovate and Improve. Long Range Planning 38, 299-319.

Carey, C., (2014) The CCAFS regional scenarios programme: external evaluation report on progress towards programme outcomes. CGIAR Research Program on Climate Change, Agriculture and Food Security, Copenhagen, Denmark.

Carlsson, B., Jacobsson, S., (1997) In Search of Useful Public Policies — Key Lessons and Issues for Policy Makers, in: Carlsson, B. (Ed.), Technological Systems and Industrial Dynamics. Springer US, Boston, MA, pp. 299-315.

Caron, P., Ferrero y de Loma-Osorio, G., Nabarro, D., Hainzelin, E., Guillou, M., Andersen, I., Arnold, T., Astralaga, M., Beukeboom, M., Bickersteth, S., Bwalya, M., Caballero, P., Campbell, B.M., Divine, N., Fan, S., Frick, M., Friis, A., Gallagher, M., Halkin, J.-P., Hanson, C., Lasbennes, F., Ribera, T., Rockstrom, J., Schuepbach, M., Steer, A., Tutwiler, A., Verburg, G. (2018) Food systems for sustainable development: proposals for a profound four-part transformation. Agronomy for Sustainable Development 38, 41.

Cash, D., Clark, W., (2001) From Science to Policy: Assessing the Assessment Process. Harvard University, John F. Kennedy School of Government.

Cash, D.W., Adger, W.N., Berkes, F., Garden, P., Lebel, L., Olsson, P., Pritchard, L., Young, O. (2006) Scale and Cross-Scale Dynamics: Governance and Information in a Multilevel World. Ecology and Society 11.

Cash, D.W., Belloy, P.G. (2020) Salience, Credibility and Legitimacy in a Rapidly Shifting World of Knowledge and Action. Sustainability 12, 7376.

Cash, D.W., Clark, W.C., Alcock, F., Dickson, N.M., Eckley, N., Guston, D.H., Jäger, J., Mitchell, R.B. (2003) Knowledge systems for sustainable development. Proceedings of the National Academy of Sciences 100, 8086-8091.

Cash, D.W., Clark, W.C., Alcock, F., Dickson, N.M., Eckley, N., Jäger, J. (2002) Salience, Credibility, Legitimacy and Boundaries: Linking Research, Assessment and Decision Making. KSG Working Papers Series RWP02.

CCAFS, (2009) Climate Change, Agriculture and Food Security. A CGIAR Challenge Program. The Alliance of the CGIAR Centers, Earth System Science Partnership, Rome and Paris.

CCAFS, (2011a) Annual Report to CGIAR Consortium. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Copenhagen, Denmark.

CCAFS, (2011b) Program Plan Summary. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Copenhagen, Denmark.

CCAFS, (2013) Engagement and Communications Strategy. CGIAR Research Program on Climate Change, Agriculture and Food Security.

CCAFS, (2016) Climate Change, Agriculture and Food Security: Full Proposal 2017-2022. CGIAR Research Program on Climate Change, Agriculture and Food Security, Copenhagen.

CCAFS, (2017) CCAFS Phase II Capacity Development Strategy. CGIAR Research Program on Climate Change, Agriculture and Food Security, Wageningen, The Netherlands.

CCAFS, (2020) 2019 Annual Report to CGIAR Consortium. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Wageningen, The Netherlands.

CGIAR, (2007), CGIAR News.

CGIAR, (2014) Climate and Sustainable Development Goals Begin on The Farm, New York, USA.

CGIAR, (2016) STRATEGY AND RESULTS FRAMEWORK 2016-2030: REDEFINING HOW CGIAR DOES BUSINESS UNTIL 2030.

CGIAR, (2019) Meeting Summary - 9th System Council Meeting. CGIAR, Chengdu, China.

Chaudhury, M., Vervoort, J., Kristjanson, P., Ericksen, P., Ainslie, A. (2013) Participatory scenarios as a tool to link science and policy on food security under climate change in East Africa. Regional Environmental Change 13, 389-398.

Chiles, R.M., Broad, G., Gagnon, M., Negowetti, N., Glenna, L., Griffin, M.A.M., Tami-Barrera, L., Baker, S., Beck, K. (2021) Democratizing ownership and participation in the 4th Industrial Revolution: challenges and opportunities in cellular agriculture. Agriculture and Human Values.

Clapp, J., Anderson, M., Rahmanian, M., Monsalve Suarez, S., (2021) An 'IPCC for Food'? How the UN Food Systems Summit is being used to advance a problematic new science-policy agenda. International Panel of Experts on Sustainable Food Systems, Brussels, Belgium.

Clark, W.C., Tomich, T.P., van Noordwijk, M., Guston, D., Catacutan, D., Dickson, N.M., McNie, E. (2016a) Boundary work for sustainable development: Natural resource management at the Consultative Group on International Agricultural Research (CGIAR). Proceedings of the National Academy of Sciences 113, 4615-4622.

Clark, W.C., van Kerkhoff, L., Lebel, L., Gallopin, G.C. (2016b) Crafting usable knowledge for sustainable development. Proceedings of the National Academy of Sciences 113, 4570-4578.

Clayton, H., Culshaw, F. (2009) Science into policy: Taking part in the process. Natural Environment Research Council.

Conti, C., Zanello, G., Hall, A. (2021) Why are agri-food systems resistant to new directions of change? A systematic review. Global Food Security 31, 100576.

CoSAI, (2021) Funding Agricultural Innovation for the Global South: Does it Promote Sustainable Agricultural Intensification? Methodology Report. Commission on Sustainable Agriculture Intensification, Colombo, Sri Lanka.

Covic, N., Dobermann, A., Fanzo, J., Henson, S., Herrero, M., Pingali, P., Staal, S. (2021) All hat and no cattle: Accountability following the UN food systems summit. Global Food Security 30, 100569.

Cramer, L., Thornton, P., Dinesh, D., Jat, M., Khatri-Chhetri, A., Laderach, P., Martinez-Baron, D., Ouedraogo, M., Partey, S., Totin, E., (2018) Lessons on bridging the science-policy divide for climate change action in developing countries. CGIAR Research Program on Climate Change, Agriculture and Food Security, Wageningen.

Crippa, M., Solazzo, E., Guizzardi, D., Monforti-Ferrario, F., Tubiello, F.N., Leip, A. (2021) Food systems are responsible for a third of global anthropogenic GHG emissions. Nature Food.

Cunliffe, A.L. (2016) “On Becoming a Critically Reflexive Practitioner” Redux:What Does It Mean to Be Reflexive? Journal of Management Education 40, 740-746.

Cvitanovic, C., Hobday, A.J., van Kerkhoff, L., Wilson, S.K., Dobbs, K., Marshall, N.A. (2015) Improving knowledge exchange among scientists and decision-makers to facilitate the adaptive governance of marine resources: A review of knowledge and research needs. Ocean & Coastal Management 112, 25-35.

Danner, J., Coopersmith, M. (2015) The other" F" word: how smart leaders, teams, and entrepreneurs put failure to work. John Wiley & Sons.

De Silva, P.U.K., K. Vance, C., (2017) Assessing the Societal Impact of Scientific Research, in: De Silva, P.U.K., Vance, C.K. (Eds.), Scientific Scholarly Communication: The Changing Landscape. Springer International Publishing, Cham, pp. 117-132.

Deichmann, U., Goyal, A., Mishra, D., (2016) Will digital technologies transform agriculture in developing countries? The World Bank.

den Boer, A.C.L., Kok, K.P.W., Gill, M., Breda, J., Cahill, J., Callenius, C., Caron, P., Damianova, Z., Gurinovic, M., Lähteenmäki, L., Lang, T., Sonnino, R., Verburg, G., Westhoek, H., Cesuroglu, T., Regeer, B.J., Broerse, J.E.W. (2020) Research and innovation as a catalyst for food system transformation. Trends in Food Science & Technology.

Dentoni, D., Bitzer, V., Schouten, G. (2018) Harnessing Wicked Problems in Multi-stakeholder Partnerships. Journal of Business Ethics 150, 333-356.

Dentoni, D., Waddell, S., Waddock, S. (2017) Pathways of transformation in global food and agricultural systems: implications from a large systems change theory perspective. Current Opinion in Environmental Sustainability 29, 8-13.

Dilling, L., Lemos, M.C. (2011) Creating usable science: Opportunities and constraints for climate knowledge use and their implications for science policy. Global Environmental Change 21, 680-689.

Dinesh, D., (2019) Summary of the 5th Global Science Conference on Climate-Smart Agriculture, 5th Global Science Conference on Climate-Smart Agriculture. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Bali, Indonesia.

Dinesh, D., Hegger, D.L.T., Vervoort, J.M., Driessen, P.P.J. (2021) A Changing Climate for Knowledge Generation in Agriculture: Lessons to Institutionalise Science-Policy Engagement. Frontiers in Climate 3.

Dinesh, D., Zougmore, R., Vervoort, J., Totin, E., Thornton, P., Solomon, D., Shirsath, P., Pede, V., Lopez Noriega, I., Läderach, P., Körner, J., Hegger, D., Girvetz, E., Friis, A., Driessen, P., Campbell, B. (2018) Facilitating Change for Climate-Smart Agriculture through Science-Policy Engagement. Sustainability 10, 2616.

Douthwaite, B., Apgar, J.M., Schwarz, A.-M., Attwood, S., Senaratna Sellamuttu, S., Clayton, T. (2017) A new professionalism for agricultural research for development. International Journal of Agricultural Sustainability 15, 238-252.

Douthwaite, B., Hoffecker, E. (2017) Towards a complexity-aware theory of change for participatory research programs working within agricultural innovation systems. Agricultural Systems 155, 88-102.

Dunlop, C.A. (2017) Policy learning and policy failure: definitions, dimensions and intersections. Policy & Politics 45, 3-18.

Dunn, G., Laing, M. (2017) Policy-makers perspectives on credibility, relevance and legitimacy (CRELE). Environmental Science & Policy 76, 146-152.

Earl, S., Carden, F., Smutylo, T. (2001) Outcome mapping: Building learning and reflection into development programs. IDRC, Ottawa, ON, CA.

Edelenbos, J., van Buuren, A., van Schie, N. (2011) Co-producing knowledge: joint knowledge production between experts, bureaucrats and stakeholders in Dutch water management projects. Environmental Science & Policy 14, 675-684.

Edmondson, A.C. (2011) Strategies for learning from failure. Harvard Business Review 89, 48-55.

El Bilali, H. (2019) Research on agro-food sustainability transitions: A systematic review of research themes and an analysis of research gaps. Journal of Cleaner Production 221, 353-364.

El Bilali, H. (2020) Transition heuristic frameworks in research on agro-food sustainability transitions. Environment, Development and Sustainability 22, 1693-1728.

Elzen, B., Barbier, M., Cerf, M., Grin, J., (2012) Stimulating transitions towards sustainable farming systems, in: Darnhofer, I., Gibbon, D., Dedieu, B. (Eds.), Farming Systems Research into the 21st Century: The New Dynamic. Springer Netherlands, Dordrecht, pp. 431-455.

Elzen, B., Wieczorek, A. (2005) Transitions towards sustainability through system innovation. Technological Forecasting and Social Change 72, 651-661.

Fanzo, J., Covic, N., Dobermann, A., Henson, S., Herrero, M., Pingali, P., Staal, S. (2020) A research vision for food systems in the 2020s: Defying the status quo. Global Food Security 26, 100397-100397.

Fanzo, J., Haddad, L., Schneider, K.R., Béné, C., Covic, N.M., Guarin, A., Herforth, A.W., Herrero, M., Sumaila, U.R., Aburto, N.J., Amuyunzu-Nyamongo, M., Barquera, S., Battersby, J., Beal, T., Bizzotto Molina, P., Brusset, E., Cafiero, C., Campeau, C., Caron, P., Cattaneo, A., Conforti, P., Davis, C., DeClerck, F.A.J., Elouafi, I., Fabi, C., Gephart, J.A., Golden, C.D., Hendriks, S.L., Huang, J., Laar, A., Lal, R., Lidder, P., Loken, B., Marshall, Q., Masuda, Y.J., McLaren, R., Neufeld, L.M., Nordhagen, S., Remans, R., Resnick, D., Silverberg, M., Torero Cullen, M., Tubiello, F.N., Vivero-Pol, J.-L., Wei, S., Rosero Moncayo, J. (2021) Viewpoint: Rigorous monitoring is necessary to guide food system transformation in the countdown to the 2030 global goals. Food Policy 104, 102163.

FAO, (2015) The State of Food and Agriculture 2015 in Brief (SOFA), State of Food and Agriculture in Brief. Food and Agriculture Organisation of the United Nations, Rome, Italy.

FAO, (2018) The State of Food Security and Nutrition in the World 2018: Building climate resilience for food security and nutrition. Food and Agriculture Organisation of the United Nations, Rome.

FAO, (2020) The State of Food Security and Nutrition in the World 2020: Transforming food systems for affordable healthy diets. Food and Agriculture Organisation of the United Nations, Rome.

Fazey, I., Evely, A.C., Reed, M.S., Stringer, L.C., Kruijsen, J., White, P.C.L., Newsham, A., Jin, L., Cortazzi, M., Phillipson, J., Blackstock, K., Entwistle, N., Sheate, W., Armstrong, F., Blackmore, C., Fazey, J., Ingram, J., Gregson, J.O.N., Lowe, P., Morton, S., Trevitt, C. (2012) Knowledge exchange: a review and research agenda for environmental management. Environmental Conservation 40, 19-36.

Fazey, I., Schäpke, N., Caniglia, G., Hodgson, A., Kendrick, I., Lyon, C., Page, G., Patterson, J., Riedy, C., Strasser, T., Verveen, S., Adams, D., Goldstein, B., Klaes, M., Leicester, G., Linyard, A., McCurdy, A., Ryan, P., Sharpe, B., Silvestri, G., Abdurrahim, A.Y., Abson, D., Adetunji, O.S., Aldunce, P., Alvarez-Pereira, C., Amparo, J.M., Amundsen, H., Anderson, L., Andersson, L., Asquith, M., Augenstein, K., Barrie, J., Bent, D., Bentz, J., Bergsten, A., Berzonsky, C., Bina, O., Blackstock, K., Boehnert, J., Bradbury, H., Brand, C., Böhme, J., Bøjer, M.M., Carmen, E., Charli-Joseph, L., Choudhury, S., Chunhachoti-ananta, S., Cockburn, J., Colvin, J., Connon, I.L.C., Cornforth, R., Cox, R.S., Cradock-Henry, N., Cramer, L., Cremaschi, A., Dannevig, H., Day, C.T., de Lima Hutchison, C., de Vrieze, A., Desai, V., Dolley, J., Duckett, D., Durrant, R.A., Egermann, M., Elsner, E., Fremantle, C., Fullwood-Thomas, J., Galafassi, D., Gobby, J., Golland, A., González-Padrón, S.K., Gram-Hanssen, I., Grandin, J., Grenni, S., Lauren Gunnell, J., Gusmao, F., Hamann, M., Harding, B., Harper, G., Hesselgren, M., Hestad, D., Heykoop, C.A., Holmén, J., Holstead, K., Hoolohan, C., Horcea-Milcu, A.-I., Horlings, L.G., Howden, S.M., Howell, R.A., Huque, S.I., Inturias Canedo, M.L., Iro, C.Y., Ives, C.D., John, B., Joshi, R., Juarez-Bourke, S., Juma, D.W., Karlsen, B.C., Kliem, L., Kläy, A., Kuenkel, P., Kunze, I., Lam, D.P.M., Lang, D.J., Larkin, A., Light, A., Luederitz, C., Luthe, T., Maguire, C., Mahecha-Groot, A.-M., Malcolm, J., Marshall, F., Maru, Y., McLachlan, C., Mmbando, P., Mohapatra, S., Moore, M.-L., Moriggi, A., Morley-Fletcher, M., Moser, S., Mueller, K.M., Mukute, M., Mühlemeier, S., Naess, L.O., Nieto-Romero, M., Novo, P., O'Brien, K., O'Connell, D.A., O'Donnell, K., Olsson, P., Pearson, K.R., Pereira, L., Petridis, P., Peukert, D., Phear, N., Pisters, S.R., Polsky, M., Pound, D., Preiser, R., Rahman, M.S., Reed, M.S., Revell, P., Rodriguez, I., Rogers, B.C., Rohr, J., Nordbø Rosenberg, M., Ross, H., Russell, S., Ryan, M., Saha, P., Schleicher, K., Schneider, F., Scoville-Simonds, M., Searle, B., Sebhatu, S.P., Sesana, E., Silverman, H., Singh, C., Sterling, E., Stewart, S.-J., Tàbara, J.D., Taylor, D., Thornton, P., Tribaldos, T.M., Tschakert, P., Uribe-Calvo, N., Waddell, S., Waddock, S., van der Merwe, L., van Mierlo, B., van Zwanenberg, P., Velarde, S.J., Washbourne, C.-L., Waylen, K., Weiser, A., Wight, I., Williams, S., Woods, M., Wolstenholme, R., Wright, N., Wunder, S., Wyllie, A., Young, H.R. (2020) Transforming knowledge systems for life on Earth: Visions of future systems and how to get there. Energy Research & Social Science 70, 101724.

Feinstein, O.N., (2014) Assessment of Climate Services work by the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Copenhagen, Denmark.

Felt, U., Igelsböck, J., Schikowitz, A., Völker, T. (2016) Transdisciplinary Sustainability Research in Practice:Between Imaginaries of Collective Experimentation and Entrenched Academic Value Orders. Science, Technology, & Human Values 41, 732-761.

Feola, G. (2015) Societal transformation in response to global environmental change: A review of emerging concepts. Ambio 44, 376-390.

Foray, D., (1997) Generation and distribution of technological knowledge: Incentives, norms, and institutions, in: Edquist, C. (Ed.), Systems of Innovation: Technologies, Institutions and Organisations. Pinter, London, pp. 64-85.

Forbes, H., Quested, T., O'Connor, C., (2021) Food Waste Index Report 2021. United Nations Environment Programme, Nairobi, Kenya.

Fowler Jr, F.J. (2013) Survey research methods. Sage publications.

Fuglie, K. (2017) R&D Capital, R&D Spillovers, and Productivity Growth in World Agriculture. Applied Economic Perspectives and Policy 40, 421-444.

Fuglie, K., Gautam, M., Goyal, A., Maloney, W.F. (2020) Harvesting Prosperity: Technology and Productivity Growth in Agriculture. World Bank, Washington DC.

Fullana i Palmer, P., Puig, R., Bala, A., Baquero, G., Riba, J., Raugei, M. (2011) From Life Cycle Assessment to Life Cycle Management. Journal of Industrial Ecology 15, 458-475.

Funtowicz, S., Ravetz, J. (1997) Environmental problems, post-normal science, and extended peer communities. Études et Recherches sur les Systèmes Agraires et le Développement, 169-175.

Gates, B., (2019) You've probably never heard of CGIAR, but they are essential to feeding our future. Gates Notes, Seattle, United States of America.

GCA, (2019) Adapt Now: a Global Call for Leadership on Climate Resilience. Global Commission on Adaptation, Washington DC and Rotterdam.

GCF, (2020) GCF Sector Guide on Agriculture and Food Security. Green Climate Fund, Seoul.

GCSA, (2019) History of the CSA Global Science Conference. Global CSA Conference, Bali, Indonesia.

Gill, G.J., (2014) An assessment of the impact of laser-assisted precision land levelling technology as a component of climate-smart agriculture in the state of Haryana, India. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Copenhagen, Denmark.

Gluckman, P. (2016) The science–policy interface. Science 353, 969-969.

Gluckman, P.D., Bardsley, A., Kaiser, M. (2021) Brokerage at the science–policy interface: from conceptual framework to practical guidance. Humanities and Social Sciences Communications 8, 84.

Guest, G., MacQueen, K.M., Namey, E.E. (2011) Applied thematic analysis. Sage.

Guest, G., Namey, E.E., Mitchell, M.L., (2013) Participant Observation, in: Guest, G., Namey, E.E., Mitchell, M.L. (Eds.), Collecting Qualitative Data: A Field Manual for Applied Research. SAGE Publications, Ltd, 55 City Road, London.

Gupta, S.K., Gunasekaran, A., Antony, J., Gupta, S., Bag, S., Roubaud, D. (2019) Systematic literature review of project failures: Current trends and scope for future research. Computers & Industrial Engineering 127, 274-285.

Guston, D.H. (2001) Boundary Organisations in Environmental Policy and Science: An Introduction. Science, Technology, & Human Values 26, 399-408.

Haines, A., Kuruvilla, S., Borchert, M. (2004) Bridging the implementation gap between knowledge and action for health. Bulletin of the World Health Organisation 82, 724-731.

Hainzelin, E., Caron, P., Place, F., Alpha, A., Dury, S., Echeverria, R., Harding, A., (2021) How could science-policy interfaces boost food system transformation?, FSS Brief. IFPRI, Washington, United States of America, p. 16.

Hall, A., Dijkman, J., (2019) Public Agricultural Research in an Era of Transformation: The Challenge of Agri-Food System Innovation. CGIAR Independent Science and Partnership Council (ISPC) Secretariat and Commonwealth Scientific and Industrial Research Organisation (CSIRO), Rome and Canberra.

Haman, M., Hertzum, M. (2019) Collaboration in a distributed research program. Journal of Documentation 75, 334-348.

Harding, A., (2014) What is the difference between an impact and an outcome? Impact is the longer term effect of an outcome, Impact of Social Sciences Blog. London School of Economics and Political Science, London.

Hariharan, V.K., Mittal, S., Rai, M., Agarwal, T., Kalvaniya, K.C., Stirling, C.M., Jat, M.L. (2020) Does climate-smart village approach influence gender equality in farming households? A case of two contrasting ecologies in India. Climatic Change 158, 77-90.

Heath, R. (2009) Celebrating failure: The power of taking risks, making mistakes, and thinking big. Red Wheel/Weiser.

Hebinck, A., Zurek, M., Achterbosch, T., Forkman, B., Kuijsten, A., Kuiper, M., Nørrung, B., Veer, P.v.t., Leip, A. (2021) A Sustainability Compass for policy navigation to sustainable food systems. Global Food Security 29, 100546.

Hegger, D., Alexander, M., Raadgever, T., Priest, S., Bruzzone, S. (2020) Shaping flood risk governance through science-policy interfaces: Insights from England, France and the Netherlands. Environmental Science & Policy 106, 157-165.

Hegger, D., Dieperink, C. (2014) Toward successful joint knowledge production for climate change adaptation: lessons from six regional projects in the Netherlands. Ecology and Society 19.

Hegger, D., Lamers, M., Van Zeijl-Rozema, A., Dieperink, C. (2012) Conceptualising joint knowledge production in regional climate change adaptation projects: success conditions and levers for action. Environmental Science & Policy 18, 52-65.

Heink, U., Marquard, E., Heubach, K., Jax, K., Kugel, C., Neßhöver, C., Neumann, R.K., Paulsch, A., Tilch, S., Timaeus, J., Vandewalle, M. (2015) Conceptualizing credibility, relevance and legitimacy for evaluating the effectiveness of science–policy interfaces: Challenges and opportunities. Science and Public Policy 42, 676-689.

Herdt, R.W. (2012) People, institutions, and technology: A personal view of the role of foundations in international agricultural research and development 1960–2010. Food Policy 37, 179-190.

Hering, J.G., Dzombak, D.A., Green, S.A., Luthy, R.G., Swackhamer, D. (2014) Engagement at the Science–Policy Interface. Environmental Science & Technology 48, 11031-11033.

Hermans, F., Roep, D., Klerkx, L. (2016) Scale dynamics of grassroots innovations through parallel pathways of transformative change. Ecological Economics 130, 285-295.

Herrero, M., Thornton, P.K., Mason-D'Croz, D., Palmer, J., Bodirsky, B.L., Pradhan, P., Barrett, C.B., Benton, T.G., Hall, A., Pikaar, I., Bogard, J.R., Bonnett, G.D., Bryan, B.A., Campbell, B.M., Christensen, S., Clark, M., Fanzo, J., Godde, C.M., Jarvis, A., Loboguerrero, A.M., Mathys, A., McIntyre, C.L., Naylor, R.L., Nelson, R., Obersteiner, M., Parodi, A., Popp, A., Ricketts, K., Smith, P., Valin, H., Vermeulen, S.J., Vervoort, J., van Wijk, M., van Zanten, H.H.E., West, P.C., Wood, S.A., Rockström, J. (2021) Articulating the effect of food systems innovation on the Sustainable Development Goals. The Lancet Planetary Health 5, e50-e62.

Herrero, M., Thornton, P.K., Mason-D'Croz, D., Palmer, J., Benton, T.G., Bodirsky, B.L., Bogard, J.R., Hall, A., Lee, B., Nyborg, K., Pradhan, P., Bonnett, G.D., Bryan, B.A., Campbell, B.M., Christensen, S., Clark, M., Cook, M.T., de Boer, I.J.M., Downs, C., Dizyee, K., Folberth, C., Godde, C.M., Gerber, J.S., Grundy, M., Havlik, P., Jarvis, A., King, R., Loboguerrero, A.M., Lopes, M.A., McIntyre, C.L., Naylor, R., Navarro, J., Obersteiner, M., Parodi, A., Peoples, M.B., Pikaar, I., Popp, A., Rockström, J., Robertson, M.J., Smith, P., Stehfest, E., Swain, S.M., Valin, H., van Wijk, M., van Zanten, H.H.E., Vermeulen, S., Vervoort, J., West, P.C. (2020) Innovation can accelerate the transition towards a sustainable food system. Nature Food 1, 266-272.

Hetherington, E.D., Phillips, A.A. (2020) A Scientist's Guide for Engaging in Policy in the United States. Frontiers in Marine Science 7.

Hinson, R., Lensink, R., Mueller, A. (2019) Transforming agribusiness in developing countries: SDGs and the role of FinTech. Current Opinion in Environmental Sustainability 41, 1-9.

Holmes, J., Clark, R. (2008) Enhancing the use of science in environmental policy-making and regulation. Environmental Science & Policy 11, 702-711.

Hoogerwerf, A. (1990) Reconstructing policy theory. Evaluation and Program Planning 13, 285-291.

Hoppe, R., Wesselink, A., Cairns, R. (2013) Lost in the problem: the role of boundary organisations in the governance of climate change. Wiley Interdisciplinary Reviews: Climate Change 4, 283-300.

Hounkonnou, D., Kossou, D., Kuyper, T.W., Leeuwis, C., Nederlof, E.S., Röling, N., Sakyi-Dawson, O., Traoré, M., van Huis, A. (2012) An innovation systems approach to institutional change: Smallholder development in West Africa. Agricultural Systems 108, 74-83.

Howden, S.M., Soussana, J.-F., Tubiello, F.N., Chhetri, N., Dunlop, M., Meinke, H. (2007) Adapting agriculture to climate change. Proceedings of the National Academy of Sciences 104, 19691-19696.

Ingram, J. (2011) A food systems approach to researching food security and its interactions with global environmental change. Food Security 3, 417-431.

Ingram, J. (2018) Agricultural transition: Niche and regime knowledge systems' boundary dynamics. Environmental Innovation and Societal Transitions 26, 117-135.

Interview-B, (2019) Interview with CCAFS management team member on failures in science-policy engagement efforts, in: Dinesh, D. (Ed.).

Interview-C, (2019) Interview with CCAFS management team member on failures in science-policy engagement efforts, in: Dinesh, D. (Ed.).

Interview-F, (2019) Interview with CCAFS management team member on failures in science-policy engagement efforts, in: Dinesh, D. (Ed.).

Interviewee-O, (2020) Institutionalising high-quality knowledge generation for climate change adaptation in agriculture, in: Dinesh, D. (Ed.).

Interviewee-P, (2020) Institutionalising high-quality knowledge generation for climate change adaptation in agriculture, in: Dinesh, D. (Ed.).

Interviewee-Q, (2020) Institutionalising high-quality knowledge generation for climate change adaptation in agriculture, in: Dinesh, D. (Ed.).

Interviewee-R, (2020) Institutionalising high-quality knowledge generation for climate change adaptation in agriculture, in: Dinesh, D. (Ed.).

Interviewee-S, (2020) Institutionalising high-quality knowledge generation for climate change adaptation in agriculture, in: Dinesh, D. (Ed.).

Interviewee-T, (2020) Institutionalising high-quality knowledge generation for climate change adaptation in agriculture, in: Dinesh, D. (Ed.).

Interviewee-U, (2020) Institutionalising high-quality knowledge generation for climate change adaptation in agriculture, in: Dinesh, D. (Ed.).

Interviewee-V, (2020) Institutionalising high-quality knowledge generation for climate change adaptation in agriculture, in: Dinesh, D. (Ed.).

Interviewee-W, (2020) Institutionalising high-quality knowledge generation for climate change adaptation in agriculture, in: Dinesh, D. (Ed.).

Interviewee-X, (2020) Institutionalising high-quality knowledge generation for climate change adaptation in agriculture, in: Dinesh, D. (Ed.).

Interviewee-Y, (2020) Institutionalising high-quality knowledge generation for climate change adaptation in agriculture, in: Dinesh, D. (Ed.).

Interviewee-Z, (2020) Institutionalising high-quality knowledge generation for climate change adaptation in agriculture, in: Dinesh, D. (Ed.).

IPCC, (2019) Climate Change and Land: An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Intergovernmental Panel on Climate Change, Geneva.

IPCC, (2021) Climate Change 2021: The Physical Science Basis. Intergovernmental Panel on Climate Change.

IPES-FOOD, (2020) 'One CGIAR' with two tiers of influence? The case for a real restructuring of global ag-research centres International Panel of Experts on Sustainable Food Systems Brussels.

ISPC, C., (2017) Quality of Research for Development in the CGIAR Context. CGIAR Independent Science and Partnership Council, Rome.

Janse, G. (2008) Communication between forest scientists and forest policy-makers in Europe — A survey on both sides of the science/policy interface. Forest Policy and Economics 10, 183-194.

Jobbins, G., Pillot, D., (2013) Review of CGIAR Research Programme 7: Climate Change, Agriculture and Food Security. European Commission and International Fund for Agricultural Development, Copenhagen, Denmark.

Jones, N.A., Jones, H., Walsh, C. (2008) Political Science?-Strengthening Science-policy Dialogue in Developing Countries. Overseas Development Institute London, United Kingdom.

Kamanda, J., Birner, R., Bantilan, C. (2017) The "efficient boundaries" of international agricultural research: A conceptual framework with empirical illustrations. Agricultural Systems 150, 78-85.

Kates, R.W., Clark, W.C., Corell, R., Hall, J.M., Jaeger, C.C., Lowe, I., McCarthy, J.J., Schellnhuber, H.J., Bolin, B., Dickson, N.M., Faucheux, S., Gallopin, G.C., Grübler, A., Huntley, B., Jäger, J., Jodha, N.S., Kasperson, R.E., Mabogunje, A., Matson, P., Mooney, H., Moore, B., O'Riordan, T., Svedin, U. (2001) Sustainability Science. Science 292, 641-642.

Kawasaki, G. (2010) Reality Check: The Irreverent Guide to Outsmarting, Outmanaging, and Outmarketing Your Competition. Strategic Direction 26.

Keeley, J., Scoones, I. (2014) Understanding environmental policy processes: Cases from Africa. Routledge.

Kemp, R., Schot, J., Hoogma, R. (1998) Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management. Technology Analysis & Strategic Management 10, 175-198.

Khanna, R., Guler, I., Nerkar, A. (2016) Fail Often, Fail Big, and Fail Fast? Learning from Small Failures and R&D Performance in the Pharmaceutical Industry. Academy of Management Journal 59, 436-459.

Kilelu, C.W., Klerkx, L., Leeuwis, C. (2013) Unravelling the role of innovation platforms in supporting co-evolution of innovation: Contributions and tensions in a smallholder dairy development programme. Agricultural Systems 118, 65-77.

Kingsley, G. (1993) The Use of Case Studies in R&D Impact Evaluations.

Kirchhoff, C.J., Lemos, M.C., Dessai, S. (2013) Actionable Knowledge for Environmental Decision Making: Broadening the Usability of Climate Science. Annual Review of Environment and Resources 38, 393-414.

Kislov, R. (2018) Selective permeability of boundaries in a knowledge brokering team. Public Administration 96, 817-836.

Kläy, A., Zimmermann, A.B., Schneider, F. (2015) Rethinking science for sustainable development: Reflexive interaction for a paradigm transformation. Futures 65, 72-85.

Klerkx, L., Begemann, S. (2020) Supporting food systems transformation: The what, why, who, where and how of mission-oriented agricultural innovation systems. Agricultural Systems 184, 102901.

Klerkx, L., Rose, D. (2020) Dealing with the game-changing technologies of Agriculture 4.0: How do we manage diversity and responsibility in food system transition pathways? Global Food Security 24, 100347.

Klerkx, L., van Mierlo, B., Leeuwis, C., (2012) Evolution of systems approaches to agricultural innovation: concepts, analysis and interventions, in: Darnhofer, I., Gibbon, D., Dedieu, B. (Eds.), Farming Systems Research into the 21st Century: The New Dynamic. Springer Netherlands, Dordrecht, pp. 457-483.

Knight, A.T., Cowling, R.M., Rouget, M., Balmford, A., Lombard, A.T., Campbell, B.M. (2008) Knowing But Not Doing: Selecting Priority Conservation Areas and the Research–Implementation Gap. Conservation Biology 22, 610-617.

Knott, A.M., Posen, H.E. (2005) Is failure good? Strategic Management Journal 26, 617-641.

Koetz, T., Farrell, K.N., Bridgewater, P. (2012) Building better science-policy interfaces for international environmental governance: assessing potential within the Intergovernmental Platform for Biodiversity and Ecosystem Services. International Environmental Agreements: Politics, Law and Economics 12, 1-21.

Kok, K.P.W., den Boer, A.C.L., Cesuroglu, T., van der Meij, M.G., de Wildt-Liesveld, R., Regeer, B.J., Broerse, J.E.W. (2019) Transforming Research and Innovation for Sustainable Food Systems—A Coupled-Systems Perspective. Sustainability 11, 7176.

Kothari, A., MacLean, L., Edwards, N. (2009) Increasing capacity for knowledge translation: understanding how some researchers engage policy makers. Evidence & Policy: A Journal of Research, Debate and Practice 5, 33-51.

Kristjanson, P., Jost, C., Vervoort, J., Ferdous, N., Schubert, C., (2014) Moving from Knowledge to Action: Blogging research and outcome highlights. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Copenhagen, Denmark.

Kristjanson, P., Reid, R.S., Dickson, N., Clark, W.C., Romney, D., Puskur, R., MacMillan, S., Grace, D. (2009) Linking international agricultural research knowledge with action for sustainable development. Proceedings of the National Academy of Sciences 106, 5047-5052.

Kunert, S., (2018) Introduction, in: Kunert, S. (Ed.), Strategies in Failure Management: Scientific Insights, Case Studies and Tools. Springer International Publishing, Cham, pp. 1-6.

Kuylenstierna, J., Forrester, J., Williams, E., Dyke, A., (2021) Assessing SEI's policy engagement. Stockholm Environment Institute, Stockholm, Sweden.

Laborde, D., Porciello, J., Smaller, C. (2020) Ceres2030: Sustainable Solutions to End Hunger Summary Report.

Lacey, J., Howden, M., Cvitanovic, C., Colvin, R.M. (2018) Understanding and managing trust at the climate science–policy interface. Nature Climate Change 8, 22-28.

Lahsen, M., Turnhout, E. (2021) How norms, needs, and power in science obstruct transformations towards sustainability. Environmental Research Letters 16, 025008.

Laing, M., Wallis, P.J. (2016) Scientists versus policy-makers: Building capacity for productive interactions across boundaries in the urban water sector. Environmental Science & Policy 66, 23-30.

Lang, D.J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M., Thomas, C.J. (2012) Transdisciplinary research in sustainability science: practice, principles, and challenges. Sustainability Science 7, 25-43.

Lawton, J.H. (2007) Ecology, politics and policy. Journal of Applied Ecology 44, 465-474.

Leach, M., Nisbett, N., Cabral, L., Harris, J., Hossain, N., Thompson, J. (2020) Food politics and development. World Development 134, 105024.

Leeuw, F.L. (2003) Reconstructing Program Theories: Methods Available and Problems to be Solved. American Journal of Evaluation 24, 5-20.

Leeuwis, C., Boogaard, B.K., Atta-Krah, K. (2021) How food systems change (or not): governance implications for system transformation processes. Food Security 13, 761-780.

Leeuwis, C., Klerkx, L., Schut, M. (2018) Reforming the research policy and impact culture in the CGIAR: Integrating science and systemic capacity development. Global Food Security 16, 17-21.

Lemos, M.C., Agrawal, A. (2006) Environmental Governance. Annual Review of Environment and Resources 31, 297-325.

Leoncini, R. (2017) How to Learn From Failure. Organisational Creativity, Learning, Innovation and the Benefit of Failure. Organisational Creativity, Learning, Innovation and the Benefit of Failure (April 1, 2017). Rutgers Business Review 2.

Leroy, P., Driessen, P., Vierssen, W.v. (2010) Climate, Science, Society and Politics: Multiple Perspectives on Interactions and Change.

Lipper, L., Thornton, P., Campbell, B.M., Baedeker, T., Braimoh, A., Bwalya, M., Caron, P., Cattaneo, A., Garrity, D., Henry, K., Hottle, R., Jackson, L., Jarvis, A., Kossam, F., Mann, W., McCarthy, N., Meybeck, A., Neufeldt, H., Remington, T., Sen, P.T., Sessa, R., Shula, R., Tibu, A., Torquebiau, E.F. (2014) Climate-smart agriculture for food security. Nature Climate Change 4, 1068.

Loboguerrero, A.M., Martinez-Baron, D., Birch, J., Bong, B.B., Campbell, B., Dinesh, D., Hansen, J., Huyer, S., Korner, J., Meza, L., Millan, A., Rabbinge, R., Reddy, M., Sunga, I., Thornton, P., (2018) Feeding the World in a Changing Climate: An Adaptation Roadmap for Agriculture. Global Commission on Adaptation.

Loboguerrero, A.M., Thornton, P., Wadsworth, J., Campbell, B.M., Herrero, M., Mason-D'Croz, D., Dinesh, D., Huyer, S., Jarvis, A., Millan, A., Wollenberg, E., Zebiak, S. (2020) Perspective article: Actions to reconfigure food systems. Global Food Security 26, 100432.

Long, T.B., Blok, V., Coninx, I. (2016) Barriers to the adoption and diffusion of technological innovations for climate-smart agriculture in Europe: evidence from the Netherlands, France, Switzerland and Italy. Journal of Cleaner Production 112, 9-21.

Loorbach, D., Frantzeskaki, N., Avelino, F. (2017) Sustainability Transitions Research: Transforming Science and Practice for Societal Change. Annual Review of Environment and Resources 42, 599-626.

Lowder, S.K., Skoet, J., Singh, S., (2014) What do we really know about the number and distribution of farms and family farms worldwide?, ESA Working Papers. Food and Agriculture Organisation of the United Nations, Rome.

Lybbert, T.J., Sumner, D.A. (2012) Agricultural technologies for climate change in developing countries: Policy options for innovation and technology diffusion. Food Policy 37, 114-123.

Maas, T.Y., Montana, J., van der Hel, S., Kowarsch, M., Tuinstra, W., Schoolenberg, M., Mahony, M., Lucas, P.L., Kok, M., Bakkes, J., Turnhout, E. (2021) Effectively empowering: A different look at bolstering the effectiveness of global environmental assessments. Environmental Science & Policy 123, 210-219.

Macleod, C.J.A., Blackstock, K.L., Haygarth, P.M. (2008) Mechanisms to Improve Integrative Research at the Science-Policy Interface for Sustainable Catchment Management. Ecology and Society 13.

Mangnus, A.C., Oomen, J., Vervoort, J.M., Hajer, M.A. (2021) Futures literacy and the diversity of the future. Futures 132, 102793.

Marshall, N., Adger, N., Attwood, S., Brown, K., Crissman, C., Cvitanovic, C., De Young, C., Gooch, M., James, C., Jessen, S., Johnson, D., Marshall, P., Park, S., Wachenfeld, D., Wrigley, D. (2017) Empirically derived guidance for social scientists to influence environmental policy. PLOS ONE 12, e0171950.

Maru, Y.T., Sparrow, A., Butler, J.R.A., Banerjee, O., Ison, R., Hall, A., Carberry, P. (2018) Towards appropriate mainstreaming of "Theory of Change" approaches into agricultural research for development: Challenges and opportunities. Agricultural Systems 165, 344-353.

Mazzucato, M. (2021) Mission economy: A moonshot guide to changing capitalism. Penguin

McCalla, A.F., (2014) CGIAR Reform-Why So Difficult? Review, Reform, Renewal, Restructuring, Reform Again and then" The New CGIAR"-So Much Talk and So Little Basic Structural Change-Why?, Agriculture and Resource Economics Working Papers. Department of Agricultural and Resource Economics, University of California, Davis.

McCalla, A.F., (2017) The Relevance of the CGIAR in a Modernizing World: Or Has It Been Reformed ad infinitum into Dysfunctionality?, in: Pingali, P., Feder, G. (Eds.), Agriculture and Rural Development in a Globalizing World: Challenges and Opportunities. Routledge, Abingdon, p. 353.

McCullough, E.B., Matson, P.A. (2016) Evolution of the knowledge system for agricultural development in the Yaqui Valley, Sonora, Mexico. Proceedings of the National Academy of Sciences 113, 4609-4614.

McGrath, R.G. (2011) Failing by design. Harvard Business Review 89, 76-83, 137.

McLeod, A., Berdegué, J., Teng, P., Zimm, S., (2017) Evaluation of Partnerships in CGIAR. Independent Evaluation Arrangement of CGIAR, Rome.

McNie, E.C. (2007) Reconciling the supply of scientific information with user demands: an analysis of the problem and review of the literature. Environmental Science & Policy 10, 17-38.

Meadowcroft, J. (2007) Who is in Charge here? Governance for Sustainable Development in a Complex World*. Journal of Environmental Policy & Planning 9, 299-314.

Meinke, H., Nelson, R., Kokic, P., Stone, R., Selvaraju, R., Baethgen, W. (2006) Actionable climate knowledge: from analysis to synthesis. Climate Research 33, 101-110.

Melchior, I.C., Newig, J. (2021) Governing Transitions towards Sustainable Agriculture—Taking Stock of an Emerging Field of Research. Sustainability 13, 528.

Meynard, J.-M., Jeuffroy, M.-H., Le Bail, M., Lefèvre, A., Magrini, M.-B., Michon, C. (2017) Designing coupled innovations for the sustainability transition of agrifood systems. Agricultural Systems 157, 330-339.

Michaels, S. (2009) Matching knowledge brokering strategies to environmental policy problems and settings. Environmental Science & Policy 12, 994-1011.

Millan, A., Limketkai, B., Guarnaschelli, S., (2019) Financing the Transformation of Food Systems Under a Changing Climate. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Wageningen, The Netherlands.

Mills, A.J., Durepos, G., Wiebe, E. (2010) Encyclopedia of Case Study Research, Thousand Oaks, California.

Mollinga, P.P. (2010) Boundary Work and the Complexity of Natural Resources Management. Crop Science 50, S-1-S-9.

Múnera, C., van Kerkhoff, L. (2019) Diversifying knowledge governance for climate adaptation in protected areas in Colombia. Environmental Science & Policy 94, 39-48.

Murendo, C., Wollni, M., (2015) Ex-post impact assessment of fertilizer microdosing as a climate-smart technology in sub-Saharan Africa. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Copenhagen, Denmark.

Nagy, E., Ransiek, A., Schäfer, M., Lux, A., Bergmann, M., Jahn, T., Marg, O., Theiler, L. (2020) Transfer as a reciprocal process: How to foster receptivity to results of transdisciplinary research. Environmental Science & Policy 104, 148-160.

Nelson, R., Kokic, P., Crimp, S., Martin, P., Meinke, H., Howden, S.M., de Voil, P., Nidumolu, U. (2010) The vulnerability of Australian rural communities to climate variability and change: Part II—Integrating impacts with adaptive capacity. Environmental Science & Policy 13, 18-27.

Nelson, V., Morton, J., (2020) CRP 2020 Reviews: Climate Change, Agriculture and Food Security. CGIAR Advisory Services Shared Secretariat, Rome, Italy.

Neßhöver, C., Timaeus, J., Wittmer, H., Krieg, A., Geamana, N., van den Hove, S., Young, J., Watt, A. (2013) Improving the Science-Policy Interface of Biodiversity Research Projects. GAIA - Ecological Perspectives for Science and Society 22, 99-103.

Nigussie, Z., Tsunekawa, A., Haregeweyn, N., Adgo, E., Cochrane, L., Floquet, A., Abele, S. (2018) Applying Ostrom's institutional analysis and development framework to soil and water conservation activities in north-western Ethiopia. Land Use Policy 71, 1-10.

Nilsen, P., Ståhl, C., Roback, K., Cairney, P. (2013) Never the twain shall meet?-a comparison of implementation science and policy implementation research. Implementation Science 8, 63.

O'Brien, K.L., Leichenko, R.M. (2003) Winners and Losers in the Context of Global Change. Annals of the Association of American Geographers 93, 89-103.

OECD (2021) Agricultural Policy Monitoring and Evaluation 2021.

Oliver, K., Kothari, A., Mays, N. (2019) The dark side of coproduction: do the costs outweigh the benefits for health research? Health Research Policy and Systems 17, 33.

Opdam, P. (2010) Learning science from practice. Landscape Ecology 25, 821-823.

Ostrom, E. (2011) Background on the Institutional Analysis and Development Framework. Policy Studies Journal 39, 7-27.

Ostrom, E., Gardner, R., Walker, J., Walker, J.M., Walker, J. (1994) Rules, games, and common-pool resources. University of Michigan Press.

Oxford, U.o., (2021) Guidance note 1: What we mean by policy engagement. University of Oxford, Oxford.

Ozgediz, S. (2012) The CGIAR at 40: Institutional evolution of the world's premier agricultural research network. CGIAR Fund Office, Washington DC.

Palazzo, A., Vervoort, J.M., Mason-D'Croz, D., Rutting, L., Havlík, P., Islam, S., Bayala, J., Valin, H., Kadi Kadi, H.A., Thornton, P., Zougmore, R. (2017) Linking regional stakeholder scenarios and shared socioeconomic pathways: Quantified West African food and climate futures in a global context. Global Environmental Change 45, 227-242.

Patterson, J., Schulz, K., Vervoort, J., van der Hel, S., Widerberg, O., Adler, C., Hurlbert, M., Anderton, K., Sethi, M., Barau, A. (2017) Exploring the governance and politics of transformations towards sustainability. Environmental Innovation and Societal Transitions 24, 1-16.

Penfield, T., Baker, M.J., Scoble, R., Wykes, M.C. (2014) Assessment, evaluations, and definitions of research impact: A review. Research Evaluation 23, 21-32.

Pharo, P., Oppenheim, J., Laderchi, C.R., Benson, S., (2019) Growing Better: Ten Critical Transitions to Transform Food and Land Use. Food and Land Use Coalition

Phillips, L.M., (2017) Policy Engagement and Civil Society: The Case of IFAD, in: Marchetti, R. (Ed.), Partnerships in International Policy-Making: Civil Society and Public Institutions in European and Global Affairs. Palgrave Macmillan UK, London, pp. 89-105.

Pigford, A.-A.E., Hickey, G.M., Klerkx, L. (2018) Beyond agricultural innovation systems? Exploring an agricultural innovation ecosystems approach for niche design and development in sustainability transitions. Agricultural Systems 164, 116-121.

Pillot, D., Dugue, M.-J., (2018) CGIAR Review 2018: CCAFS Case study: Climate Change, Agriculture and Food Security European Commission and Internation Fund for Agricultural Development.

Pingali, P., Kelley, T., (2007) Chapter 45 The Role of International Agricultural Research in Contributing to Global Food Security and Poverty Alleviation: The case of the CGIAR, in: Evenson, R., Pingali, P. (Eds.), Handbook of Agricultural Economics. Elsevier, pp. 2381-2418.

Popa, F., Guillermin, M., Dedeurwaerdere, T. (2015) A pragmatist approach to transdisciplinarity in sustainability research: From complex systems theory to reflexive science. Futures 65, 45-56.

Porter, J.R., Xie, L., Challinor, A.J., Cochrane, K., Howden, S.M., Iqbal, M.M., Lobell, D.B., Travasso, M.I., (2014) Chapter 7: Food security and food production systems. Cambridge University Press.

Poteete, A.R., Janssen, M.A., Ostrom, E. (2010) Working together: collective action, the commons, and multiple methods in practice. Princeton University Press.

Proust, K., Newell, B., Brown, H., Capon, A., Browne, C., Burton, A., Dixon, J., Mu, L., Zarafu, M. (2012) Human Health and Climate Change: Leverage Points for Adaptation in Urban Environments. International Journal of Environmental Research and Public Health 9, 2134-2158.

Radaelli, C.M. (1995) The role of knowledge in the policy process. Journal of European Public Policy 2, 159-183.

Rajkotia, Y. (2018) Beware of the success cartel: a plea for rational progress in global health. BMJ Global Health 3, e001197.

Ramirez, L.F., Belcher, B.M. (2020) Crossing the science-policy interface: Lessons from a research project on Brazil nut management in Peru. Forest Policy and Economics 114, 101789.

Rawe, T., Antonelli, M., Chatrchyan, A., Clayton, T., Fanzo, J., Gonsalves, J., Matthews, A., Nierenberg, D., Zurek, M., (2019) Transforming food systems under climate change: Local to global policy as a catalyst for change, CCAFS Working Paper. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Wageningen, The Netherlands.

Reardon, T., Echeverria, R., Berdegué, J., Minten, B., Liverpool-Tasie, S., Tschirley, D., Zilberman, D. (2019) Rapid transformation of food systems in developing regions: Highlighting the role of agricultural research & innovations. Agricultural Systems 172, 47-59.

Reddy, V.R., (2015) Ex-post Impact Assessment of the Study:'Impact of Climate Change on Water Resources and Agriculture in Sri Lanka'. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Copenhagen, Denmark.

Resnick, E. (2001) Defining Engagement. Journal of International Affairs 54, 551-566.

Richards, M., Bruun, T.B., Campbell, B.M., Gregersen, L.E., Huyer, S., Kuntze, V., Madsen, S.T., Oldvig, M.B., Vasileiou, I., (2015) How countries plan to address agricultural adaptation and mitigation. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Copenhagen.

Richards, M., Bruun, T.B., Campbell, B.M., Gregersen, L.E., Huyer, S., Kuntze, V., Madsen, S.T., Oldvig, M.B., Vasileiou, I., (2016) How countries plan to address agricultural adaptation and mitigation: An analysis of Intended Nationally Determined Contributions. CCAFS dataset, in: CGIAR Research Program on Climate Change, A.a.F.S.C. (Ed.), Copenhagen.

Rijswijk, K., Klerkx, L., Bacco, M., Bartolini, F., Bulten, E., Debruyne, L., Dessein, J., Scotti, I., Brunori, G. (2021) Digital transformation of agriculture and rural areas: A socio-cyber-physical system framework to support responsibilisation. Journal of Rural Studies 85, 79-90.

Robinson, M.K., Flood, B.P., (2013) Governance and Management Review. CGIAR Research Program on Climate Change, Agriculture and Food Security, Copenhagen, Denmark.

Rogers, P.J. (2008) Using Programme Theory to Evaluate Complicated and Complex Aspects of Interventions. Evaluation 14, 29-48.

Roodhof, A.M., Duncan, J.A.B., Candel, J.J.L., Turnhout, E., Maas, T.Y., (2021) Reflections on the global science-policy interface for food systems. PBL Netherlands Environmental Assessment Agency.

Rose, D.C., Brotherton, P.N.M., Owens, S., Pryke, T. (2016) Honest advocacy for nature: presenting a persuasive narrative for conservation. Biodiversity and Conservation, 1-21.

Roy-Macauley, H., Izac, A.M., Rijsberman, F., (2016) The role of CGIAR in agricultural research for development in Africa South of the Sahara. International Food Policy Research Institute, Washington, pp. 401-422.

Rudd, M.A., Lawton, R.N. (2013) Scientists' prioritization of global coastal research questions. Marine Policy 39, 101-111.

Salmon, R.A., Priestley, R.K., Goven, J. (2017) The reflexive scientist: an approach to transforming public engagement. Journal of Environmental Studies and Sciences 7, 53-68.

Samian, M., Movahedi, R., Ansari, E., Asadi, M. (2016) Analyzing the Role of Agricultural Beneficiaries in Sustainable Management of Natural Resources and Environment (Case of Hamadan County). International Journal of Agricultural Management and Development 6, 387-395.

Sarewitz, D., Pielke, R.A. (2007) The neglected heart of science policy: reconciling supply of and demand for science. Environmental Science & Policy 10, 5-16.

Sarkki, S., Balian, E., Heink, U., Keune, H., Nesshöver, C., Niemelä, J., Tinch, R., Van Den Hove, S., Watt, A., Waylen, K.A., Young, J.C. (2019) Managing science-policy interfaces for impact: Interactions within the environmental governance meshwork. Environmental Science & Policy.

Sarkki, S., Niemelä, J., Tinch, R., van den Hove, S., Watt, A., Young, J. (2014) Balancing credibility, relevance and legitimacy: A critical assessment of trade-offs in science–policy interfaces. Science and Public Policy 41, 194-206.

Sarkki, S., Tinch, R., Niemelä, J., Heink, U., Waylen, K., Timaeus, J., Young, J., Watt, A., Neßhöver, C., van den Hove, S. (2015) Adding 'iterativity' to the credibility, relevance, legitimacy: A novel scheme to highlight dynamic aspects of science–policy interfaces. Environmental Science & Policy 54, 505-512.

Sauermann, H., Vohland, K., Antoniou, V., Balázs, B., Göbel, C., Karatzas, K., Mooney, P., Perelló, J., Ponti, M., Samson, R., Winter, S. (2020) Citizen science and sustainability transitions. Research Policy 49, 103978.

Saviano, M., Barile, S., Farioli, F., Orecchini, F. (2019) Strengthening the science–policy–industry interface for progressing toward sustainability: a systems thinking view. Sustainability Science 14, 1549-1564.

Sayer, J., Cassman, K.G. (2013) Agricultural innovation to protect the environment. Proceedings of the National Academy of Sciences 110, 8345-8348.

Schmidt-Traub, G., Obersteiner, M., Mosnier, A. (2019) Fix the broken food system in three steps. Nature.

Schot, J., Geels, F.W. (2008) Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy. Technology Analysis & Strategic Management 20, 537-554.

Schot, J., Steinmueller, W.E. (2018) Three frames for innovation policy: R&D, systems of innovation and transformative change. Research Policy 47, 1554-1567.

Schuetz, T., Förch, W., Thornton, P., Vasileiou, I., (2017) Pathway to impact: supporting and evaluating enabling environments for research for development, in: Uitto, J.I., Puri, J., vandenBerg, R.D. (Eds.), Evaluating climate change action for sustainable development. Springer, Washington, DC, USA; New Delhi, India; Leidschendam, The Netherlands, pp. 53-79.

Schuetz, T., Förch, W., Thornton, P.K., Wollenberg, E.K., Hansen, J., Jarvis, A., Coffey, K., Bonilla-Findji, O., Loboguerrero Rodriguez, A.-M., Martinez Baron, D., Aggarwal, P.K., Sebastian, L.S., Zougmore, R., Kinyangi, J., Vermeulen, S., Radeny, M., Moussa, A., Sajise, A., Khatri-Chhetri, A., Richards, M., Jost, Christine C. , Jay, A., (2014) Lessons in theory of change from a series of regional planning workshops. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Copenhagen, Denmark.

Schut, M., Klerkx, L., Kamanda, J., Sartas, M., Leeuwis, C., (2019) Innovation Platforms: Synopsis of Innovation Platforms in Agricultural Research and Development☆, in: Ferranti, P., Berry, E.M., Anderson, J.R. (Eds.), Encyclopedia of Food Security and Sustainability. Elsevier, Oxford, pp. 510-515.

Scoble, R., Dickson, K., Hanney, S., Rodgers, G.J. (2010) Institutional strategies for capturing socio-economic impact of academic research. Journal of Higher Education Policy and Management 32, 499-510.

Searchinger, T., Waite, R., Hanson, C., Ranganathan, J., Dumas, P. (2019) Creating a sustainable food future: A menu of solutions to feed nearly 10 billion people by 2050. WRI.

Shaw, D.J. (2010) The World Food Council: The Rise and Fall of a United Nations Body. Canadian Journal of Development Studies / Revue canadienne d'études du développement 30, 663-694.

Shepherd, M., Turner, J.A., Small, B., Wheeler, D. (2020) Priorities for science to overcome hurdles thwarting the full promise of the 'digital agriculture' revolution. Journal of the Science of Food and Agriculture 100, 5083-5092.

Singh, G.G., Farjalla, V.F., Chen, B., Pelling, A.E., Ceyhan, E., Dominik, M., Alisic, E., Kerr, J., Selin, N.E., Bassioni, G., Bennett, E., Kemp, A.H., Chan, K.M. (2019) Researcher engagement in policy deemed societally beneficial yet unrewarded. Frontiers in Ecology and the Environment 17, 375-382.

Sitkin, S.B. (1992) Learning Through Failure : The Strategy of Small Losses. Research in Organisational Behavior 14, 231-266.

Sitko, N.J., Babu, S.C., Hoffman, B. (2017) Practitioner's guidebook and toolkit for agricultural policy reform: The PMCA approach to strategic policy engagement. Intl Food Policy Res Inst.

Skrimizea, E., Lecuyer, L., Bunnefeld, N., Butler, J.R.A., Fickel, T., Hodgson, I., Holtkamp, C., Marzano, M., Parra, C., Pereira, L., Petit, S., Pound, D., Rodríguez, I., Ryan, P., Staffler, J., Vanbergen, A.J., Van den Broeck, P., Wittmer, H., Young, J.C., (2020) Chapter Seven - Sustainable agriculture: Recognizing the potential of conflict as a positive driver for transformative change, in: Bohan, D.A., Vanbergen, A.J. (Eds.), Advances in Ecological Research. Academic Press, pp. 255-311.

Smink, M.M., Hekkert, M.P., Negro, S.O. (2015) Keeping sustainable innovation on a leash? Exploring incumbents' institutional strategies. Business Strategy and the Environment 24, 86-101.

Smith, G.R., (2014) CGIAR Research Program on Climate Change, Agriculture and Food Security Program Theme 3: Pro-Poor Climate Change Mitigation: Evaluation of 2011-2013. CGIAR Research Program on Climate Change, Agriculture and Food Security Program, Copenhagen, Denmark.

Spilsbury, M.J., Nasi, R. (2006) The interface of policy research and the policy development process: challenges posed to the forestry community. Forest Policy and Economics 8, 193-205.

Steenwerth, K.L., Hodson, A.K., Bloom, A.J., Carter, M.R., Cattaneo, A., Chartres, C.J., Hatfield, J.L., Henry, K., Hopmans, J.W., Horwath, W.R., Jenkins, B.M., Kebreab, E., Leemans, R., Lipper, L., Lubell, M.N., Msangi, S., Prabhu, R., Reynolds, M.P., Sandoval Solis, S., Sischo, W.M., Springborn, M., Tittonell, P., Wheeler, S.M., Vermeulen, S.J., Wollenberg, E.K., Jarvis, L.S., Jackson, L.E. (2014) Climate-smart agriculture global research agenda: scientific basis for action. Agriculture & Food Security 3, 11.

Steiner, A., Aguilar, G., Bomba, K., Bonilla, J.P., Campbell, A., Echeverria, R., Gandhi, R., Hedegaard, C., Holdorf, D., Ishii, N., Quinn, K.M., Ruter, B., Sunga, I., Sukhdev, P., Verghese, S., Voegele, J., Winters, P., Campbell, B., Dinesh, D., Huyer, S., Jarvis, A., Loboguerrero, A.M., Millan, A., Thornton, P., Wollenberg, L., Zebiak, S., (2020) Actions to Transform Food Systems Under Climate Change. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Wageningen, The Netherlands.

Stone, D. (2001) Think Tanks, Global Lesson-Drawing and Networking Social Policy Ideas. Global Social Policy 1, 338-360.

Stringer, L.C., Dougill, A.J. (2013) Channelling science into policy: Enabling best practices from research on land degradation and sustainable land management in dryland Africa. Journal of Environmental Management 114, 328-335.

Stringer, L.C., Dougill, A.J., Fraser, E., Hubacek, K., Prell, C., Reed, M.S. (2006) Unpacking "participation" in the adaptive management of social–ecological systems: a critical review. Ecology and Society 11.

Stringer, L.C., Fraser, E.D.G., Harris, D., Lyon, C., Pereira, L., Ward, C.F.M., Simelton, E. (2020) Adaptation and development pathways for different types of farmers. Environmental Science & Policy 104, 174-189.

Strohmaier, R., Rioux, J., Seggel, A., Meybeck, A., Bernoux, M., Salvatore, M., Miranda, J., Agostini, A., (2016) The agriculture sectors in the Intended Nationally Determined Contributions: analysis, Environment and Natural Resources Management Working Paper. Food and Agriculture Organisation of the United Nations, Rome.

Strydom, W.F., Funke, N., Nienaber, S., Nortje, K., Steyn, M. (2010) Evidence-based policymaking: a review. South African Journal of Science 106, 17-24.

Sundbo, J., Fuglsang, L., (2006) Strategic Reflexivity as a Framework for Understanding Development in Modern Firms. How the Environment Drives Innovation, in: Sundbo, J., Gallina, A., Serin, G., Davis, J. (Eds.), Contemporary Management of Innovation: Are We Asking the Right Questions? Palgrave Macmillan UK, London, pp. 147-166.

Sundqvist, G., Gasper, D., St.Clair, A.L., Hermansen, E.A.T., Yearley, S., Øvstebø Tvedten, I., Wynne, B. (2018) One world or two? Science–policy interactions in the climate field. Critical Policy Studies 12, 448-468.

Sutherland, W.J., Bellingan, L., Bellingham, J.R., Blackstock, J.J., Bloomfield, R.M., Bravo, M., Cadman, V.M., Cleevely, D.D., Clements, A., Cohen, A.S., Cope, D.R., Daemmrich, A.A., Devecchi, C., Anadon, L.D., Denegri, S., Doubleday, R., Dusic, N.R., Evans, R.J., Feng, W.Y., Godfray, H.C.J., Harris, P., Hartley, S.E., Hester, A.J., Holmes, J., Hughes, A., Hulme, M., Irwin, C., Jennings, R.C., Kass, G.S., Littlejohns, P., Marteau, T.M., McKee, G., Millstone, E.P., Nuttall, W.J., Owens, S., Parker, M.M., Pearson, S., Petts, J., Ploszek, R., Pullin, A.S., Reid, G., Richards, K.S., Robinson, J.G., Shaxson, L., Sierra, L., Smith, B.G., Spiegelhalter, D.J., Stilgoe, J., Stirling, A., Tyler, C.P., Winickoff, D.E., Zimmern, R.L. (2012) A Collaboratively-Derived Science-Policy Research Agenda. PLOS ONE 7, e31824.

Talwar, S., Wiek, A., Robinson, J. (2011) User engagement in sustainability research. Science and Public Policy 38, 379-390.

Taneja, G., Pal, B.D., Joshi, P.K., Aggarwal, P.K., Tyagi, N.K., (2019) Farmers' Preferences for Climate-Smart Agriculture—An Assessment in the Indo-Gangetic Plain, in: Pal, B.D., Kishore, A., Joshi, P.K., Tyagi, N.K. (Eds.), Climate Smart Agriculture in South Asia: Technologies, Policies and Institutions. Springer Singapore, Singapore, pp. 91-111.

Thornton, P.K., Loboguerrero Rodriguez, A.M., Campbell, B.M., Mercado, L., Shackleton, S., Kavikumar, K., (2019) Rural livelihoods, food security and rural transformation under climate change. Global Commission on Adaptation, Rotterdam and Washington DC.

Thornton, P.K., Schuetz, T., Förch, W., Cramer, L., Abreu, D., Vermeulen, S., Campbell, B.M. (2017) Responding to global change: A theory of change approach to making agricultural research for development outcome-based. Agricultural Systems 152, 145-153.

Turner, J.A., Horita, A., Fielke, S., Klerkx, L., Blackett, P., Bewsell, D., Small, B., Boyce, W.M. (2020) Revealing power dynamics and staging conflicts in agricultural system transitions: Case studies of innovation platforms in New Zealand. Journal of Rural Studies 76, 152-162.

Turnheim, B., Asquith, M., Geels, F.W. (2020) Making sustainability transitions research policy-relevant: Challenges at the science-policy interface. Environmental Innovation and Societal Transitions 34, 116-120.

Turnheim, B., Sovacool, B.K. (2020) Forever stuck in old ways? Pluralising incumbencies in sustainability transitions. Environmental Innovation and Societal Transitions 35, 180-184.

Turnhout, E., Duncan, J., Candel, J., Maas, T.Y., Roodhof, A.M., DeClerck, F., Watson, R.T. (2021) Do we need a new science-policy interface for food systems? Science 373, 1093-1095.

Turnhout, E., Metze, T., Wyborn, C., Klenk, N., Louder, E. (2020) The politics of co-production: participation, power, and transformation. Current Opinion in Environmental Sustainability 42, 15-21.

Turnhout, E., Stuiver, M., Klostermann, J., Harms, B., Leeuwis, C. (2013) New roles of science in society: Different repertoires of knowledge brokering. Science and Public Policy 40, 354-365.

UN, (2015) Paris Agreement, in: Change, F.C.o.C. (Ed.). United Nations Framework Convention on Climate Change, Paris.

UN, (2019) World Population Prospects 2019: Highlights. United Nations.

UN, (2020a) Act now to avert COVID-19 global food emergency: Guterres. United Nations News, New York.

UN, (2020b) UN chief announces major push to transform harmful food systems. United Nations New York.

UNEP, (2017) Strengthening the Science-Policy Interface: A gap analysis. United Nations Environment Programme, Nairobi, Kenya.

van Bers, C., Delaney, A., Eakin, H., Cramer, L., Purdon, M., Oberlack, C., Evans, T., Pahl-Wostl, C., Eriksen, S., Jones, L., Korhonen-Kurki, K., Vasileiou, I. (2019) Advancing the research agenda on food systems governance and transformation. Current Opinion in Environmental Sustainability 39, 94-102.

Van den Hove, S. (2007) A rationale for science–policy interfaces. Futures 39, 807-826.

van der Hel, S. (2016) New science for global sustainability? The institutionalisation of knowledge co-production in Future Earth. Environmental Science & Policy 61, 165-175.

van Enst, W.I., (2018) Science-policy interfaces for enriched environmental decision-making: A research into the strategies of boundary work, illustrated by case studies in the Dutch Wadden Sea. Utrecht University.

Van Enst, W.I., Driessen, P.P.J., Runhaar, H.A.C. (2014) Towards productive science-policy interfaces: A research agenda. Journal of Environmental Assessment Policy and Management 16, 1450007.

van Kerkhoff, L., Lebel, L. (2006) Linking Knowledge and Action for Sustainable Development. Annual Review of Environment and Resources 31, 445-477.

Vanclay, F.M., Russell, A.W., Kimber, J. (2013) Enhancing innovation in agriculture at the policy level: The potential contribution of Technology Assessment. Land Use Policy 31, 406-411.

Vellinga, P., Hisschemöller, M., Klabbers, J.H.G., Berk, M.M., Swart, R.J., van Ulden, A.P. (1995) Climate change, policy options and research implications. Studies in Environmental Science 65, 119-134.

Vermeulen, S., Campbell, B.M., (2015) Ten principles for effective AR4D programs. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Copenhagen, Denmark.

Vermeulen, S., Zougmoré, R., Wollenberg, E., Thornton, P., Nelson, G., Kristjanson, P., Kinyangi, J., Jarvis, A., Hansen, J., Challinor, A., Campbell, B., Aggarwal, P. (2012a) Climate change, agriculture and food security: a global partnership to link research and action for low-income agricultural producers and consumers. Current Opinion in Environmental Sustainability 4, 128-133.

Vermeulen, S.J., Aggarwal, P.K., Ainslie, A., Angelone, C., Campbell, B.M., Challinor, A.J., Hansen, J.W., Ingram, J.S.I., Jarvis, A., Kristjanson, P., Lau, C., Nelson, G.C., Thornton, P.K., Wollenberg, E. (2012b) Options for support to agriculture and food security under climate change. Environmental Science & Policy 15, 136-144.

Vermeulen, S.J., Campbell, B.M., Ingram, J.S. (2012c) Climate change and food systems. Annual Review of Environment and Resources 37, 195-222.

Vermeulen, S.J., Dinesh, D., Howden, M.S., Cramer, L., Thornton, P.K. (2018) Transformation in practice: a review of empirical cases of transformational adaptation in agriculture under climate change. Frontiers in Sustainable Food Systems.

Vermeulen, S.J., Park, T., Khoury, C.K., Béné, C. (2020) Changing diets and the transformation of the global food system. Annals of the New York Academy of Sciences 1478, 3-17.

Vervoort, J.M., Bourgeois, R., Ericksen, P.J., Kok, K., Thornton, P.K., Foerch, W., Chaudhury, M., Kristjanson, P.M., (2013) Linking multi-actor futures for food systems and environmental governance, Earth System Governance Conference, Tokyo.

Vinck, D., (2017) Learning thanks to innovation failure, Critical Studies of Innovation.

von Braun, J., Birner, R. (2017) Designing Global Governance for Agricultural Development and Food and Nutrition Security. Review of Development Economics 21, 265-284.

von Schneidemesser, E., Melamed, M., Schmale, J. (2020) Prepare Scientists to Engage in Science-Policy. Earth's Future 8, e2020EF001628.

von Stamm, B., (2018) Failure in Innovation: Is There Such a Thing?, in: Kunert, S. (Ed.), Strategies in Failure Management: Scientific Insights, Case Studies and Tools. Springer International Publishing, Cham, pp. 27-45.

Wanzenböck, I., Wesseling, J.H., Frenken, K., Hekkert, M.P., Weber, K.M. (2020) A framework for mission-oriented innovation policy: Alternative pathways through the problem–solution space. Science and Public Policy 47, 474-489.

Warghade, S., (2015) Policy formulation tool use in emerging policy spheres: A developing country perspective, in: Jordan, A.J., Turnpenny, J.R. (Eds.), The Tools of Policy Formulation: Actors, Capacities, Venues and Effects, pp. 205-224.

Weber, H., Poeggel, K., Eakin, H., Fischer, D., Lang, D.J., Wehrden, H.V., Wiek, A. (2020) What are the ingredients for food systems change towards sustainability?—Insights from the literature. Environmental Research Letters 15, 113001.

Westermann, O., Förch, W., Thornton, P., Körner, J., Cramer, L., Campbell, B. (2018) Scaling up agricultural interventions: Case studies of climate-smart agriculture. Agricultural Systems 165, 283-293.

Whitty, B., (2010) An accountability framework for technological innovation, ILAC Brief. Institutional Learning and Change Initiative.

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., Jonell, M., Clark, M., Gordon, L.J., Fanzo, J., Hawkes, C., Zurayk, R., Rivera, J.A., De Vries, W., Majele Sibanda, L., Afshin, A., Chaudhary, A., Herrero, M., Agustina, R., Branca, F., Lartey, A., Fan, S., Crona, B., Fox, E., Bignet, V., Troell, M., Lindahl, T., Singh, S., Cornell, S.E., Srinath Reddy, K., Narain, S., Nishtar, S., Murray, C.J.L. (2019) Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems. The Lancet 393, 447-492.

Wittmayer, J.M., Schäpke, N. (2014) Action, research and participation: roles of researchers in sustainability transitions. Sustainability Science 9, 483-496.

WKKF, (2004) Using logic models to bring together planning, evaluation, and action: logic model development guide. W.K. Kellogg Foundation, Michigan.

Wollenberg, E., Richards, M., Smith, P., Havlík, P., Obersteiner, M., Tubiello, F.N., Herold, M., Gerber, P., Carter, S., Reisinger, A., van Vuuren, D.P., Dickie, A., Neufeldt, H., Sander, B.O., Wassmann, R., Sommer, R., Amonette, J.E., Falcucci, A., Herrero, M., Opio, C., Roman-Cuesta, R.M., Stehfest, E., Westhoek, H., Ortiz-Monasterio, I., Sapkota, T., Rufino, M.C., Thornton, P.K., Verchot, L., West, P.C., Soussana, J.-F., Baedeker, T., Sadler, M., Vermeulen, S., Campbell, B.M. (2016) Reducing emissions from agriculture to meet the 2 °C target. Global Change Biology 22, 3859-3864.

Wolmer, W., Keeley, J., Leach, M., Mehta, L., Scoones, I., Waldman, L. (2006) Understanding Policy processes: A review of IDS research on the environment. Brighton: Institute of Development Studies.

Woolcock, M.J.V. (1999) Learning from Failures in Microfinance. American Journal of Economics and Sociology 58, 17-42.

Woolthuis, R.K., Lankhuizen, M., Gilsing, V. (2005) A system failure framework for innovation policy design. Technovation 25, 609-619.

Wyborn, C., Datta, A., Montana, J., Ryan, M., Leith, P., Chaffin, B., Miller, C., Kerkhoff, L.v. (2019) Co-Producing Sustainability: Reordering the Governance of Science, Policy, and Practice. Annual Review of Environment and Resources 44, 319-346.

Wynne, B. (1993) Public uptake of science: a case for institutional reflexivity. Public Understanding of Science 2, 321-337.

Young, J.C., Waylen, K.A., Sarkki, S., Albon, S., Bainbridge, I., Balian, E., Davidson, J., Edwards, D., Fairley, R., Margerison, C., McCracken, D., Owen, R., Quine, C.P., Stewart-Roper, C., Thompson, D., Tinch, R., Van den Hove, S., Watt, A. (2014) Improving the science-policy dialogue to meet the challenges of biodiversity conservation: having conversations rather than talking at one-another. Biodiversity and Conservation 23, 387-404.

Young, O.R., King, L.A., Schroeder, H., Galaz, V., Hahn, T. (2008) Institutions and environmental change: principal findings, applications, and research frontiers. MIT press Cambridge, MA.

Zougmoré, R.B., Läderach, P., Campbell, B.M. (2021) Transforming Food Systems in Africa under Climate Change Pressure: Role of Climate-Smart Agriculture. Sustainability 13, 4305.

Zougmoré, R.B., Partey, S.T., Totin, E., Ouédraogo, M., Thornton, P., Karbo, N., Sogoba, B., Dieye, B., Campbell, B.M. (2019) Science-policy interfaces for sustainable climate-smart agriculture uptake: lessons learnt from national science-policy dialogue platforms in West Africa. International Journal of Agricultural Sustainability 17, 367-382.

Zurek, M., Hebinck, A., Selomane, O. (2021) Looking across diverse food system futures: Implications for climate change and the environment. Q Open 1.

Appendices

Appendix 1: List of case studies analysed in Chapter 2

Case No.	Title and Description
1	National Climate Change Adaptation Strategy and Second National Communications to UNFCCC: (**Sri Lanka**) *Engagement with Sri Lankan Government agencies to support the development of the National Climate Change Adaptation Strategy and the Second National Communications to UNFCCC.*
2	Agriculture gets recognised in the UNFCCC Durban Agreement (**Global**) *Engagement in UNFCCC processes to facilitate agriculture getting into the Durban Agreement.*
3	Low-cost "greenhouses" for horticulture to adapt to climate change and reduce expansion into carbon-rich grasslands (**Peru - subnational**) *Work with NGOs and subnational Government agencies to develop and scale out low cost greenhouses as an adaptation strategy.*
4	Climate-smart banana-coffee intercrop systems supported through policy (**Uganda, Rwanda, Burundi**) *Science-policy engagement efforts in Uganda, Rwanda and Burundi to stimulate the adoption of coffee-banana intercropping.*
5	African group of negotiators plays major role in agricultural negotiations in COP18 (**Regional - Africa**) *Efforts to build capacity of the African Group of Negotiators (AGN) led to African countries making joint submissions to the UNFCCC on agriculture.*
6	Findings from Commission on sustainable agriculture and climate change penetrate diverse policy forums (**Global**) *Findings from the Commission on Sustainable Agriculture informed Mexico's climate change law, Kenya's agriculture act and recommendations on climate change and food security of the Committee on World Food Security*
7	10-year USD 50 million programme focused on crop wild relative collection and pre-breeding for climate change adaptation established (**Global**) *Informing a 10-year USD 50m programme focused on crop wild relative collection and pre-breeding for climate change adaptation.*
8	Regional scenarios to guide policies, investments and institutional change (**Regional**) *Use of participatory regional scenarios by policy makers and investors in different regions.*
9	Use of climate and weather data by numerous agencies and farmers (**Regional - Africa**) *Use of research monographs on African Agriculture and Climate Change in West, East and Southern Africa to assist policymakers, researchers, NGOs.*
10	Improved rainfall thresholds for index insurance (**India - subnational**) *Supporting the efforts of the Agriculture Insurance Company of India to develop improved index based insurance schemes for various crops that led to protection of more than 50,000 rain-fed farmers from the vagaries of rainfall in one crop season alone.*
11	Linking herders to carbon markets (**China - subnational**) *Methodologies for accounting and monitoring grassland carbon sequestration approved by the Chinese Government for domestic carbon trading markets, and by the Verified Carbon Standard for global use.*
12	Beyond the climate science: CCAFS-Climate data applied by thousands of non-research users around the world (**Global**) *The CCAFS Climate portal used by NGOs, foundations, non-research international/national organisations, donors and governmental institutions to support planning and implementation efforts.*
13	IPCC adopts new methodology for wetlands greenhouse gas inventories (**Global**) *Inputs into the IPCC Wetlands Supplement, which is now mandatory for all countries preparing national GHG inventories.*
14	Climate change adaptation strategy adopted by Ethiopian government (**Ethiopia**) *The Ethiopian government's Climate Change Adaptation Strategy is informed by research outputs.*
15	National adaptation policy adopted in Nicaragua and resulting investments in coffee and cocoa sector (**Nicaragua**) *Informing the national adaptation policy in Nicaragua, which leveraged a large scale International Fund for Agricultural Development (IFAD) investment to support implementation of the policy.*
16	CCAFS informs large-scale global and national investments in food security and climate change (**Global**) *Drawing on multiple analyses, informed the allocation of over half a billion USD of international public finance (grants and loans) to food security under climate change, via close collaboration with the agencies.*
17	Cambodian climate change priorities action plan for agriculture (**Cambodia**) *The Cambodian Climate Change Priorities Action Plan for Agriculture (USD 147 million) developed in an intensive collaboration with CCAFS over 9 months.*

18	Scaling Climate-Smart Villages (**India - subnational**) *CSVs scaled up by the Indian state of Maharashtra, and considered by Ministry of Panchayati Raj (local level development) in local development plans.*
19	FEDEAAROZ[#] incorporates climate information in farm extension systems (**Colombia - subnational**) *Research findings prompted Colombia's rice producers' federation (FEDEAAROZ) to incorporate climate information in farm extension systems. A decision not to plant in Cordoba – informed by seasonal forecasts and big data – prevented 1,800 ha of rice crop loss (saving USD 3.5m in input costs).*
20	Inputs into the IPCC fifth assessment report (**Global**) *Inputs into the chapter on food production and food security and summary for policy makers, has far reaching influence on policy makers globally, providing the evidence base for informed decision making.*
21	Shamba Shape Up (SSU) and increasing use of CSA information (**Regional – East Africa**) *Informing content of popular TV reality show which presents scientific findings to smallholders, with average viewership of 9 million a month.*
22	IMPACT model used in OECD global and regional policy analysis (**Global**) *Continued collaboration with OECD improves capacity to estimate and analyse climate change impacts.*
23	CIAT/CCAFS science contributes to programming and implementation of about 75 million USD IFAD financing for farmers' resilience (**Uganda, Comoros, Liberia**) *Informing programming and implementation of about USD 75 million IFAD financing for farmers' resilience.*
24	Climate-Smart Villages scaled out in Haryana (**India - subnational**) *In India, the State Government of Haryana launched a programme to pilot 500 climate smart villages in the rice-wheat systems districts of the state.*
25	Scenario-guided policy development in 8 countries (**Honduras, Cambodia, Bangladesh, Tanzania, Uganda, Burkina Faso, Colombia and Ghana**) *Support to formulate a range of agriculture, climate and development policies and plans, in Honduras, Cambodia, Bangladesh, Tanzania, Uganda, Burkina Faso, Colombia and Ghana*
26	The impact of climate information services in Senegal (**Senegal**) *Seasonal forecasts transmitted nationwide through 82 rural community radio stations and SMS, potentially reaching 7.4 million rural people across Senegal.*
27	Agriculture is not excluded from the post-2015 UNFCCC agreement in Paris (**Global**) *Work with policy and research partners towards ensuring that agriculture was not excluded from the post-2015 UNFCCC agreement announced in Paris in December 2015.*
28	Scaling climate-smart dairy practices (**Kenya**) *CCAFS research was used for the dissemination of climate-smart feeding and husbandry practices among 600,000 farmers who are members of six producers' organisations.*
29	Scientifically-designed index insurance protects a million Maharashtra farmers from increasing extreme rainfall events (**India - subnational**) *Development of new region and crop specific rainfall triggers applied to provide rainfall risk cover to crops of almost one million farmers.*
30	CIAT-CCAFS CSA Profiles in Kenya drove national/county plans, informed USD 250 million World Bank investment (**Kenya**) *Informed the development of the USD 250 million Kenya Climate Smart Agriculture Project.*
31	330,000 farmers in Honduras and Colombia use tailored seasonal forecasts and recommendations to adapt to climate (**Honduras**, **Colombia**) *Ministries of Agriculture of Honduras and Colombia are reaching-up to 330.000 farmers through 9 Local Technical Agro-climatic Committees (LTACs). LTACs provide recommendations generated through local-scientific knowledge-exchange using agro-climatic information to support decision-making.*
32	Adoption of digital system for emergency response data collection and decision-making (**Costa Rica**) *Support in the adoption of a data collection and analysis system to document USD 57.6 million damage of Hurricane Otto. The new system reduced response time and allowed more in-depth data analysis.*
33	The CCAFS Climate-Smart Village approach inspired a World Bank funded CSA project (**Niger**) *The learning agenda capitalized from AR4D in Kampa Zarma CSV served to inform the design of a USD 111 million World Bank-funded project on climate-smart agriculture in Niger.*
34	Scaling of Climate Smart Villages across 38 districts of Bihar (**India -subnational**) *CSA practices have been mainstreamed in the Government of Bihar's investment and agricultural development plan targeting climate smart villages (CSVs) to be implemented across all 38 districts.*

FEDEAAROZ is Colombia's rice producers' federation

* Shamba Shape Up is a popular television show in East Africa, which promotes agricultural practices to enable farmers to makeover their farms.

Appendix 2: Questionnaire used for survey on failures and challenges (Chapter 3)

Learning from challenges and lack of success is an important aspect of scientific endeavour. This questionnaire aims to capture lessons from challenges faced within science policy engagement efforts of CCAFS projects. This is not part of formal evaluations, and the aim is to capture insights which are not captured through formal reporting, for lesson learning with a paper being written summarizing the findings.

All responses are anonymous, but we would like to have interviews with a sample of project leaders, and if you would like to be interviewed, please provide your email address at the end.

1. We are looking for cases where you have encountered challenges or lack of success in science-policy engagement efforts, as we want to learn from these instances. Science policy engagement efforts are interpreted broadly, to include engagement in sub-national, national, and international policy frameworks, as well as policies/strategies/investments of international institutions, private sector and farmer organisations. In either your current or past science-policy engagement efforts, have you encountered challenges or lack of success? If you answer NO, the survey will end for you.

- Yes/No
- If Yes, what were these challenges or lack of success? Please describe and if possible identify the reasons why there were challenges or lack of success.: ....

2. The perceived credibility of research outputs (i.e. that research outputs are authoritative and trusted) is considered to be a key success factor in science-policy engagement. In your experience, were the challenges due to difficulty in demonstrating credibility to partners?
    - Yes/No
        i. If Yes, Please describe the challenges encountered in ensuring salience and efforts which you undertook to address these ....

3. Were challenges associated with research goals, questions, and outputs not being aligned/salient with the needs of decision makers targeted?
    - Yes/No

- If Yes, Please describe the challenges encountered in ensuring salience and efforts which you undertook to address these...

4. Were challenges encountered because decision makers did not find the research to be fair, balanced, and representing diverse interests?
   - Yes/No
   - If Yes, What issues did the decision makers have with the research?..

5. How did you communicate uncertainty to decision makers? ....
6. Were there intermediaries (e.g. brokers or boundary organisations) involved in your engagement efforts?
   - Yes/No
   - If Yes, who were the intermediaries you engaged with and what role did they play?...
   - If No, would the presence of intermediaries have improved your ability to achieve an outcome? ....
7. During your engagement process, did you encounter power dynamics at play?
   - Yes/No
   - If Yes, how did you navigate these?..

8. Did your policy partner(s) have adequate institutional capacity to take on board research findings?
   - Yes/No
   - If No, what capacity gaps existed? Please describe:.................................

9. If your engagement efforts failed to realise the expected outcome, what were the three top reasons for this?
   - ....
   - ....
   - ....
10. Is there anything else you would like to share regarding these topics?

11. Would you be willing to be part of a longer (30 minute) interview to discuss these topics further?
    - Yes/No
    - If Yes, please enter your email and we will contact you.

Appendix 3: Interview questions - lessons from challenges and failures at the interface of science and policy for climate action in agriculture (Chapter 3)

Each interview topic was introduced with an open-ended question. Text between brackets was used to explain the question if necessary. Text in bulleted lists was used to ask follow-up questions, but only if needed.

1. How do you understand failure in science-policy engagement efforts? (Based on a review of literature and a survey of CCAFS projects, we understand failures in science-policy engagement efforts as instances where expected outcomes are not realised)
    - How do you understand the relationship between challenges and failures? (We understand challenges and failures to be closely related to each other, with challenges being early warning signs of potential failure of science-policy engagement efforts. In some cases, these challenges or early warning signs can be navigated through adaptive management, but in other cases, these become fail factors, leadings to efforts failing.)
2. As part of your role in the design of the CCAFS portfolio and ensuring delivery of outcomes:
    - How do you address challenges in science-policy engagement, both at the level of projects and at the programme level?
    - How do you address failures in science-policy engagement, both at the level of projects and at the programme level?
    - Can you provide specific examples?
3. What efforts do you take at the flagship/programme level to ensure that knowledge generated is salient towards the needs of decision makers? Can you provide specific examples?
4. What can be done to further strengthen efforts to enhance salience, for example through capacity building of researchers? Please provide examples where possible.
5. Lack of the right partnerships in specific contexts has been a cause of failure. What efforts do you take to ensure skills in developing and maintaining partnerships? Please provide examples where possible.
6. How do you approach projects with poor engagement and communications efforts? Please provide examples where possible.
7. How do you ensure that funding uncertainties do not disrupt science-policy engagement activities and efforts to realise outcomes? Please provide examples where possible.
8. How does CCAFS (programme, flagships, projects) approach partners with limited capacity to absorb and implement findings?
9. How does CCAFS navigate power dynamics in science-policy engagement efforts including rapid turnover among decision makers?

10. To improve science-policy engagement efforts in the context of climate action in agriculture, we propose a fivestep process to fail intelligently (1. Plan for failures, 2. Minimize risks, 3, Design efforts intelligently, 4. Make failures visible, 5. Learn from failures). To what extent can these steps be implemented in a competitive environment such as that CCAFS operates in? How do the steps differ in terms of their complexity to implement? Are there examples of successful execution of each step?
11. Is there anything else that you would like to share?

Appendix 4: Interview questions used for Chapter 4

1. **Accountability**
   1.1 In order for research results to be credible, salient and legitimate, research institutions need to be accountable to both sides of the boundary (i.e. research and action). In your view, how important is this? Do you have an example to illustrate your answer?
   1.2 In your view, how does CCAFS fare in terms of being accountable to both sides of the boundary?
2. **Participation across the boundary**
   2.1 What are your views on participation across the boundary as a strategy to institutionalise high quality knowledge generation?
   2.2 How effective do you think CCAFS has been in mobilizing participation from both sides of the boundary? Are there key successes/shortfalls that you would like to mention?
3. **Use of boundary objects (briefs, info notes, working papers, conferences, maps, models etc.)**
   3.1 What are your views on the use of boundary objects to institutionalise high quality knowledge generation?
   3.2 In your view, how well is CCAFS using boundary objects to do more outcome oriented research? Do you have any examples of boundary objects produced by CCAFS which were very good or bad, why?
4. **Translation**
   4.1 Translating research for users, helps enhance their salience. How well do you think CCAFS is translating research for users? Is there an example you would like to share?
5. **Mediation and a selectively permeable boundary**
   5.1 Mediation is a tool to balance credibility, salience and legitimacy. Have you found this to be important? Please illustrate with an example.
      5.1.1 Is this something you have observed in CCAFS?
   5.2 Do you find that CCAFS design and management enabled a selectively permeable boundary to advance action?
6. **Coordination and complementary expertise**
   6.1 In addition to enhancing the scale and scope of research, active coordination among institutions with complementary expertise produce more effective actions. In your view how does CCAFS perform on coordination and mobilizing complementary expertise? Can you provide an example?
   6.2 The external evaluation noted that CCAFS has made progress with integration of climate change research in the CGIAR, but greater integration and linking is

needed. What is missing in terms of integrated climate change research across the CGIAR?

7. **Interactions**

   7.1 What role does interactions among different actors (e.g. through CGIAR/CCAFS governance processes) play to ensure or deter the success conditions discussed above?

   7.2 What role does CCAFS leadership play in outcome orientation of the portfolio?

Appendix 5: Questionnaire used for Chapter 5

Dear Colleague,

Many thanks for attending the 5th Global Science Conference on Climate-Smart Agriculture. In order to capture your perspectives on the conference, we would appreciate it if you could fill out this short questionnaire.

1. Which of the following categories best describes your work?

    1. **Knowledge producer** (e.g. CGIAR, advanced research institutions, National Agricultural Research Systems (NARS))
    2. **Knowledge intermediary** (e.g. United Nations agencies, Non-Governmental Organisations, consultancies)
    3. **Knowledge user** (e.g. Governments, farmer organisations, investors)
    4. **Beneficiary** (e.g. farmers, businesses)
    5. Other (please specify) ....

2. What do you believe are the biggest issues faced by the food knowledge system today? i.e. where is the food knowledge system failing?
    a. ....
    b. ....
    c. ....

3. The conference focuses on six themes, please rank these in their order of importance *(1 being least important and 6 being most important)*.

Empowerment of farmer and consumer organisations, women and youth.	
Digitally enabled climate-informed services.	
Climate-resilient and low-emissions practices and technologies.	
Innovative finance to leverage public and private sector investments.	
Reshaping supply chains, food retail, marketing and procurement.	
Fostering enabling policies and institutions.	

4. For the theme that you have marked as being most important (i.e. score of 1), what are the key areas for research and action, to drive a transformation in food systems under climate change?
    a. **Key areas for research**
        i. ....
        ii. ....
        iii. ....
    b. **Key areas for action**
        i. ....
        ii. ....
        iii. ....

5. Are there additional themes which are crucial to catalyse a transformation in food systems, which the conference has not considered? What are these themes?
    a. ....
    b. ....
    c. ....

6. In your view, what are the factors that limit interaction among different players in the knowledge system?
    a. ....
    b. ....
    c. ....

7. Would you be willing to have a 30 minute call to discuss your responses and experience from the conference further? If yes, please provide your:

    Name:

    Email:

    Designation and organisation:

Thank you for your time.

Acknowledgements

I would not have imagined doing a PhD as a child, it was a dream that I wouldn't dare to dream. So thank you to Mara who inspired me to dream of doing a PhD, to Joost for making this dream possible, and to Peter and Dries who made it plausible. Without your inspiration and support, this would not have materialised.

Doing a PhD alongside a full-time job was extremely challenging and I would not have managed to do this without the support of my CCAFS supervisors, Bruce, Ana Maria and Sonja, who not only gave me the time and space to study while working, but also provided me access to their knowledge, experience and networks whenever I needed this.

I finish my PhD as CCAFS reaches its sunset stage, many thanks to all my CCAFS colleagues and friends, who provided me not just encouragement and insights, but a space to be critical and reflexive and were willing to be subjects of my research in a transparent and open manner. The insights here are a reflection of the CCAFS culture, which was that of a science movement that endeavoured to be a force for change in the world. Thanks to the CCAFS dream team including Lini, Philip, Jim, Peter, Andy, Pramod, Robert, Deissy, Leo, Laura, Doris, Sara, Evan, Alison, Leanne, Dawit, Sophia, Rhys, Vita, Angele for your support and encouragement.

I would also like to thank the co-authors of my papers and the anonymous reviewers of these papers, their comments and inputs helped me immensely in developing my research and writing skills.

This PhD dissertation chronicles my journey at the interface between science and policy, and as I reach the culmination of this journey, I decided to apply the insights generated and start a new 'think and do tank' for food and climate, which will enable me to apply lessons from this dissertation for the benefit of society. Many thanks to those who supported me to make this idea a reality including Ivo, Marcel, Lucas, Hans, Myrtille, Wijnand, Ruben and Partha. This support and encouragement gives me hope of applying lessons from this dissertation to catalyse the urgent transformation that is needed in our food systems and society.

About the author

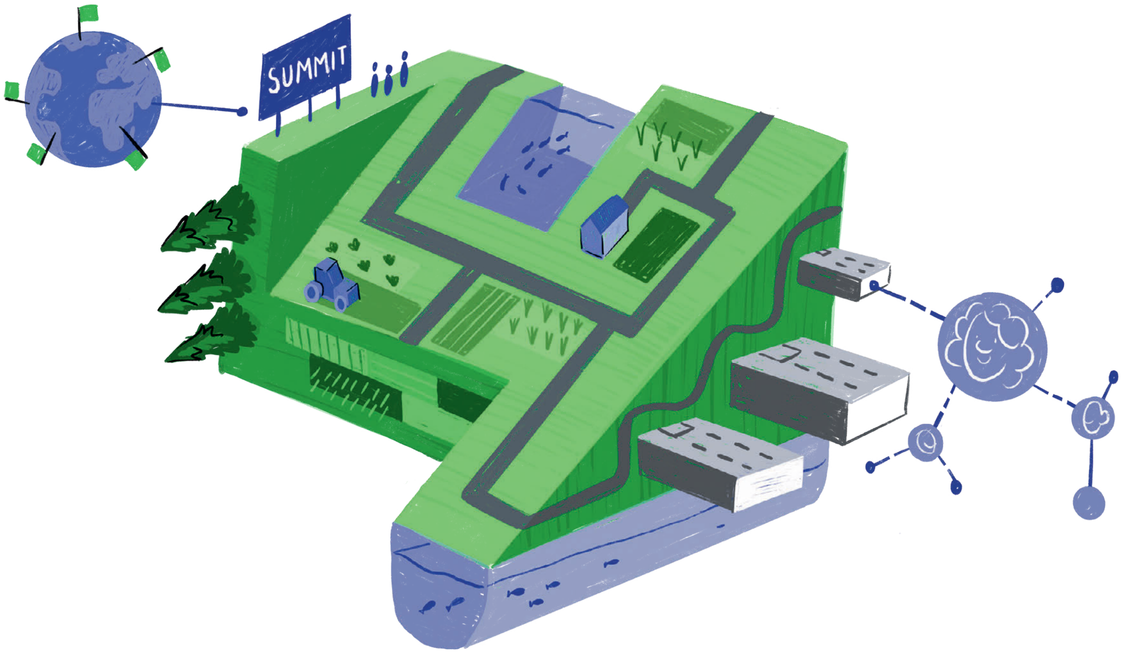
Dhanush Arayamparambil Dinesh (Dhanush), born 31 July 1986, has a Bachelor's degree in Commerce from the University of Madras, a Master's degree in Business Administration from PSG Institute of Management, and a Master's degree in Carbon Management from the University of Edinburgh. Since completion of his studies, Dhanush has worked in a number of roles within the private sector, NGOs, and the UN and CGIAR systems, in China, India, Thailand, the Netherlands and the UK. He has worked on a range of issues including forestry, environmental policy, climate change adaptation, and advocacy, at the national, regional, and global levels. At the time of completion of this dissertation, Dhanush worked at the CGIAR Research Program on Climate Change Agriculture and Food Security where he led the cross-cutting Learning Platform on Partnerships and Capacity for Scaling Climate-Smart Agriculture, and the CCAFS Program Management Unit office at Wageningen University and Research. He embarked on his PhD while working for CCAFS, as an external PhD candidate reflecting on his work on global policy engagement with a critical and academic lens.

A committed champion for climate action in food systems, Dhanush was selected as an International Climate Champion by the British Council in 2010, and since 2021 is a member of the Transformation Leaders Network of the World Economic Forum. In the lead up to the 2021 UN Climate Change Conference, Dhanush co-chaired the COP26 campaign on 'Transforming Agricultural Innovation for People, Nature and Climate', and in the lead up to the UN Food Systems Summit he led on ‘knowledge and technological innovation’ and ‘nature-positive innovation.’

Dhanush has held visiting researcher positions at the Universities of Oxford and Leeds, the International Fund for Agricultural Development, and the United Nations Environment Programme's International Ecosystem Management Partnership. He also served as a co-chair of the Scaling Positive Agriculture project of the World Business Council for Sustainable Development (WBCSD) and a Trustee and Director on the board of the Plan Vivo Foundation, an international charity for community-based payments for ecosystem services.

At COP26 in November 2021, he launched Clim-Eat, a dedicated ‘think and do tank’ to accelerate climate action in food systems by serving as a bridge between science and policy.

[ends]



illustrations: Innovation Arts