Biotechnology and the socio-biological production of vulnerability

Genetically engineered cotton in Telangana, India

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Executive Summary

The use of genetically engineered (GE) crops in agriculture has been the subject of fierce controversy worldwide for decades and remains so until today. The potentials and risks of the technology are still contested and the ongoing scholarly and public debate polarizes proponents and opponents around the world. As the fifth-largest producer of GE crops, India has become particularly involved in this controversy, not only due to its shocking waves of farmer suicides, but also as critical evidence-generating site to examine the impacts of GE crops on smallholder agriculture in the Global South. In India, the use of *Bacillus thuringiensis* (Bt) cotton is wide-spread. In the controversy surrounding Bt cotton implementation in India, on the one side, advocates of the technology stress its proclaimed agro-economic advantages, primarily involving pesticide reductions and increases in yield potentials, with ostensible effects on rural poverty reduction, particularly in countries of the Global South. Adversaries, on the other side, voice allegations associated with incalculable socio-ecological risks, including evolving pest resistances, suspected threats to agrobiodiversity, seed and food security, or farmer suicides.

The lately decelerated debate on GE agriculture has recently been reignited by the re-emergence of high infestation levels of pink bollworm (PBW), the target pest of this agricultural biotechnology, in Bt cotton fields in central and southern Indian states in the cotton season of 2015 and after. As the re-occurrence of the insect has caused unexpected collapses in yields, the controversy has now regained momentum in the country and beyond. However, resulting socio-economic implications of the implementation of the Bt technology in general, as well as the specific consequences caused by recent developments regarding the target pest's re-occurrence for cotton-farming households, have hitherto remained unaddressed in the scientific debate. Particularly the subaltern perspectives of economically marginalized actors like smallholders tend to be neglected in average values of agro-economic figures and are thus often unrepresented and remain unconsidered by relevant policy-making stakeholders.

Situated in the realm of agri-food geographies, this thesis aims to reveal these hitherto marginalized perspectives of subaltern actors that have so far been unaddressed in the scientific debate and have thus remained excluded from political decision-making processes. As such, this thesis aspires to empirically address questions on rural socioeconomy and aims to expand our knowledge on risk and vulnerability-related implications arising from the implementation of agricultural biotechnologies for Indian smallholders and the related recent developments of target pest re-occurrences. This study uses the case of Bt cotton adoption in rural Telangana in India to provide updated insights on these questions. Against the background of the objective to include marginalized perspectives of subaltern actors, this research approaches the scientific controversy on Bt cotton from a pluralized conceptualization of geographical perspectives, taking into account considerations from the fields of development geography, political economy, and economic sociology. This diversified approach not least aims to outline the complex global-local interconnections of the research object. Methodologically, I follow an exploratory research design in which I employ qualitative and quantitative research methods.

This results in four complementary parts of this study: In part 1, I investigate the livelihoods of Bt cotton farming households and their responses to the re-occurrence of the target insect using qualitative guided interviews. In part 2, I expand my focus to the structural implications of the farmers' altered vulnerability context by connecting the results of a representative survey conducted in Telangana to political economic considerations and Gramscian approaches to hegemony. In part 3, I follow the mobilities of Bt cotton-related policies in their administrative assemblage by means of a document analysis and link my findings to the results of a multivariate cluster analysis of the Telangana cotton peasantry. In part 4, I draw on expert interviews of actors involved in biotechnology innovation and outline their imagined futures by retracing their empirically accessible narratives and imaginaries involved in their future trajectories of agricultural GE innovations.

Based on the findings of this research, I conclude that the vulnerability context of cotton farming households has changed with the adoption of Bt technology. My results confirm that the PBW has indeed returned to large parts of cotton cultivation areas in Telangana. While cotton has always been considered a volatile crop due to dependencies on precipitation in non-irrigated areas, it has now become even more oscillating in terms of yield and effective income generation. For the early years of the technology implementation, farmers still reported benefits of the adoption of Bt cotton, but with the recent malfunctioning of the Bt crop and the associated re-occurrences of the target pest, unexpected collapses in yields are now ascertained. Whereas economically better-off farming households can balance such oscillations by reverting to strategies of agricultural diversification, farmers on the resource-poorer end of the economic spectrum remain trapped in loops of agricultural intensification, and are incrementally pushed into debt. Finally, they enter a cycle of dispossession, successively releasing capital and thus providing opportunities of appropriation for other actors. As a result, prevalent hegemonic structures in the neoliberal Indian Bt cotton nexus are reproduced. The economically heterogenous character of the Bt cotton peasantry also comes to the fore in regard to the compliance with Bt cotton-related refuge policies. As I show by means of a cluster analysis, especially resource-poorer farmers are pressured toward short-term profit maximization, and hence refrain from implementing cost-intensive refuge policies. Indian state authorities have hitherto failed to consider this entrepreneurial farmer logic and have further contributed to the failure of refuge crop policies, as the administrative process of policy adaption involved serious mistranslations. In order to embed these socio-economic outcomes

of agricultural biotechnology implementation on site into their discursive entanglements, this study further sheds light on the imagined futures of actors involved in the innovation of agricultural biotechnologies. As this study makes clear, the relevant actors strictly uphold a rigid imaginary of a technological fix through agricultural biotechnology while related narratives are merely adjusted. Being co-dependently intertwined with policy-making actors, the imagined futures of relevant stakeholders in turn tangibly affect agricultural biotechnology implementing smallholders.

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Table of Contents

Figures

Tables

Abbreviations

ABD	accumulation by dispossession
ABW	American bollworm
ANT	actor-network theory
BIR	built-in-refuge
Bt	Bacillus thuringiensis
CCI	Cotton Corporation of India
DBT	Department of Biotechnology
DFG	Deutsche Forschungsgemeinschaft
DFID	British Department for International Development
FAO	Food and Agriculture Organization
GE	genetically engineered
GMOs	genetically modified organisms
GEAC	Genetic Engineering Approval/Appraisal Committee
HT	herbicide tolerance
IPCC	Intergovernmental Panel on Climate Change
IRM	Insect resistance management
ISAAA	International Service for the Acquisition of Agri-Biotech Applications
KVK	*Krishi Vigyan Kendra*, governmental agricultural extension service
LC_{50}	median lethal concentration
MMBL	Mahyco Monsanto Biotech Limited
MoEF	Ministry of Environment and Forestry
NGOs	Non-governmental organizations
PI	principal investigator
PBW	pink bollworm
RIB	refuge-in-bag
RR	resistance ratio
SLA	Sustainable Livelihood Approach
SLF	Sustainable Livelihood Framework
STS	Science and Technology Studies
UNDP	United Nations Development Programme
USDA	United States Department of Agriculture

Preface

Excerpt from field notes, August 2018:

‘Following a long drive from Hyderabad, we finally arrive in Jammikunta, a town in Telangana’s Karimnagar district, in the late afternoon. After eventually getting through the dense Hyderabad traffic, leaving the Inner and Outer Ring Road behind us, we follow the straight highway through the dry landscape of the Deccan Plateau for five hours, squished in the back seat of our Uber car with one of our two translators and the rest of our luggage that did not manage to find space in the small car’s trunk. Eventually, we take a left turn in Warangal city and the highway turns into a bumpy road, hosting cows and dogs as much as cars and motorcycles. The dry landscape finally gives way to arable farm land, showing the first rice and turmeric fields and – yes, ultimately, I can spot the first cotton fields, the plants neatly cropped in even rows. As in Telangana, the crop is usually sown in the month of June, during the monsoonal period, now, in the end of August, the plants show a lush green and some even bloom with pastel-colored yellow or light pink flower buds.

The next day in the early morning, we are taking a tuk-tuk [auto rickshaw] to the previously selected village. On the way, we pass several cotton fields again, but now, from the windowless tuk-tuk, I can see the first (still green) cotton bolls. As more than ninety percent of India’s cotton crops are genetically engineered cotton, I figure that these are most likely genetically engineered crops, too. (After all, this is what we came here for and want to explore.) The plants look healthy enough, at least as far as I can tell with my amateur’s eyes. To me it seems like their appearance does not fit the rumors we have heard all around; rumors that describe severe pest outbreaks of pink bollworm in Telangana’s cotton fields.

Having reached the village, we first approach the village’s *sarpanch*, its lead and headman. After he gives us his “okay” to conduct interviews with some cotton farmers in the village, we randomly approach the first people, all turning out to be cotton farmers, to ask for an interview concerning their cultivation of Bt [*Bacillus thuringiensis*] cotton. Generously offering the four of us tea and seats just outside his house, one farmer describes his last cotton season. He said, he first heard about pink bollworm infestations in the area by a local KVK (*Krishi Vigyan Kendra*, governmental agricultural extension service) employee:

“I could not believe it initially but […] later this day I came to my field and I was very hesitant to open one of the cotton bolls in the beginning, because I thought that if I opened it, it would be wasted. But reluctantly I did and I saw that it was completely infested by pink bollworm. Later, I was so desperate that I opened nearly fifty cotton bolls just to make sure that they were not affected, but unfortunately the whole field was infected by pink bollworm.”’

1 Introduction

Worldwide, the use of genetically engineered (GE)[1] crops in agriculture has been the subject of fierce controversy for decades and remains so until today. Amidst the ongoing global scholarly and public debate, proponents and opponents are polarized as the potentials and risks of the technology are still contested (Paarlberg 2008; Glover 2010; Herring and Rao 2012; Ramani and Thutupalli 2015; Luna 2020). In the history of modern agriculture, biotechnological crops are considered the most rapidly adopted crop technology. Their importance has increased especially for developing countries, as developing countries have consistently surpassed industrial countries in GE crop cultivated acreage over the past eight years (International Service for the Acquisition of Agri-Biotech Applications (ISAAA) 2020, p. 1). As the fifth-largest producer of GE crops, India has become particularly involved in this controversy, not only due to its shocking waves of farmer suicides, but also as a critical evidence-generating site to examine the impacts of GE crops on smallholder agriculture in the Global South (ISAAA 2020, p. 2).

The only authorized but broadly implemented biotechnological crop in the country is *Bacillus thuringiensis* (Bt) cotton. The GE fiber crop is equipped with a built-in pest resistance through the genetic insertion of endotoxin-producing proteins of the soil bacterium *Bacillus thuringiensis*. These endotoxins are poisonous to certain insects when ingested, including Lepidopterans like the cotton-damaging bollworm species. In the controversy surrounding Bt cotton implementation in India, on the one side, advocates of the technology attribute successes in the country's cotton production of the early 2000s to the technology and therefore declare it as an effective tool against the Indian agrarian crisis (Qaim 2003; Kathage and Qaim 2012; Choudhary and Gaur 2015; Veettil et al. 2016). The proclaimed benefits mainly include agro-economic advantages like increases in yields and the parallel reduction of pesticide use, resulting in improved farmer profits (Qaim 2003; Kathage and Qaim 2012; Choudhary and Gaur 2015; Veettil et al. 2016). Adversaries, on the other side, accredit these positive agro-economic trends in the Indian cotton production to a plethora of factors, e.g., spreading access to irrigation facilities, and increases in the use of hybrids and fertilizers (Kranthi 2016; Kranthi and Stone 2020). Instead, they report negative social (erosion of farmers' knowledge) (Stone 2007; Flachs 2019a) and ecological side effects (outbreaks of secondary pests, pest

[1] While in the non-scientific discourse the term *genetically modified organisms* (GMOs) is more commonly used for agricultural biotechnology crops, in the scientific discourse the terminology is usually more differentiated. Here, the term *GMOs* often subsumes those organisms that are modified merely through breeding techniques, e.g., hybrids, as well as those organisms that result from engineering in labs. In order to do justice to this distinction, I refer to the latter organisms specifically as *genetically engineered*. In addition, the Indian authority responsible for agricultural biotechnology crops is called *Genetic Engineering Appraisal Committee* (GEAC).

resistances, seed insecurity) (Shiva 2010; Kranthi 2015, 2016; Gutierrez 2018; Flachs 2019a; Tabashnik and Carrière 2019; Kranthi and Stone 2020).
While the pace of research had decelerated since the 2010s, scientific and popular interest in the Bt cotton crop has lately been reignited by a recent re-emergence of the crop’s target pest, the pink bollworm (PBW). In the cotton season of 2015 and after, high levels of PBW infestation were reported for cotton fields cultivated with the current generation of Bt cotton in the central and southern Indian states of Gujarat, Madhya Pradesh, Maharashtra, Karnataka, Andhra Pradesh, and Telangana (Mohan 2017; Naik et al. 2018; Fand et al. 2019). These infestations with the target pest of Bt cotton have caused severe unexpected yield losses for cotton producers (Fand et al. 2019). As a result, the scientific controversy on the Bt cotton crop has regained momentum and intensity. Located in the realm of agri-food geographies, this research joins the scientific controversy that surrounds Bt cotton and makes contributions by expanding our knowledge on questions concerning the rural socioeconomy of Indian Bt cotton smallholders as it addresses them empirically from a pluralized geographical perspective.

1.1 Research gap, questions, and aim

Early studies on Bt cotton mostly originate from the field of agro-economics and, largely based on pre-2008 data, fall short on acknowledging the effects of the returned target pest (Qaim 2003; Kathage and Qaim 2012; Choudhary and Gaur 2015; Veettil et al. 2016). Instead, some scholars have even proclaimed sustainable positive effects of the technology on smallholder cotton production early on (Sadashivappa and Qaim 2009). While a recent agro-economic study by Kranthi and Stone (2020) indeed addresses the recent game-changing events of the target pest’s re-emergence in the Indian cotton production, it does not consider questions related to the socio-economic consequences of the recent developments for Indian smallholders. Similarly, recent entomological research has now been increasingly investigating the re-occurrence of the insect on the Indian subcontinent and its potential resistance, but again does not examine the socio-economic implications resulting from these developments for cotton producers (Tabashnik and Carrière 2019; Tabashnik et al. 2021). In addition, recent anthropological research has examined the socioecological effects arising from the technology’s implementation on Indian smallholder farms, i.e., the erosion of agrarian knowledge (Stone et al. 2014; Stone and Flachs 2017; Flachs and Stone 2018; Flachs 2019a). Equally, the socio-economic and vulnerability-related implications of the technology adoption and the recent pest infestations on Bt cotton smallholders are not explicitly addressed. Beyond that, agro-economic research, which often still dominates the scientific debate, usually addresses questions on aggregate production statistics and agronomic figures like yield averages and pesticide applications from an outcome-oriented approach. However, this focus

tends to neglect marginalized perspectives of subaltern actors, whose socio-economic environments strongly deviate from average values. Their perspectives are thus often unrepresented in agro-economic figures and hence remain unaddressed and unconsidered by relevant policy-making stakeholders.
Situated in the realm of agri-food geographies, this thesis aims to fill this lacuna by revealing such hitherto marginalized perspectives of subaltern actors that have so far been unaddressed in the scientific debate and have thus remained excluded from political decision-making processes. This thesis aspires to empirically address questions on rural socioeconomy and aims to expand our knowledge on risk and vulnerability-related implications arising from the implementation of agricultural biotechnologies for Indian smallholders and the related recent developments of target pest re-occurrences. In so doing, this research intends to fill the scientific void that has existed particularly in regard to the socio-economic impacts of the PBW re-emergence on cotton-cultivating smallholders in central and southern Indian states of cotton production. Against the background of this objective, this research approaches the scientific controversy on Bt cotton from a pluralized conceptualization of geographical perspectives, including considerations from the fields of development geography, political economy, and economic sociology. In this study, I use the case of Bt cotton adoption in rural Telangana in India to provide updated insights on these questions.
Taking an actor-oriented perspective, the study analyzes the altered vulnerability context of farming households in Telangana and puts resulting processes of economic marginalization center stage by considering structural political economic consequences of the technology's malfunctioning and the resulting landmark development of the target pest's re-occurrences. Moreover, the research intends to contribute to the scientific debate on a more abstract level by providing a critical perspective on questions concerning the mobilities of Bt cotton-related refuge policies and mistranslations involved in their administrative adaption and on-site non-compliance. Discursive ramifications that embed these political economic notions and affect the socioeconomies of rural smallholders in turn, are then explored via considerations of economic sociology related to the constitution of the imagined futures of biotechnological innovation actors through their empirically accessible narratives and imaginaries. The imagined futures of relevant stakeholders tangibly affect agricultural biotechnology implementing smallholders, as they are co-dependently intertwined with policy-making actors.

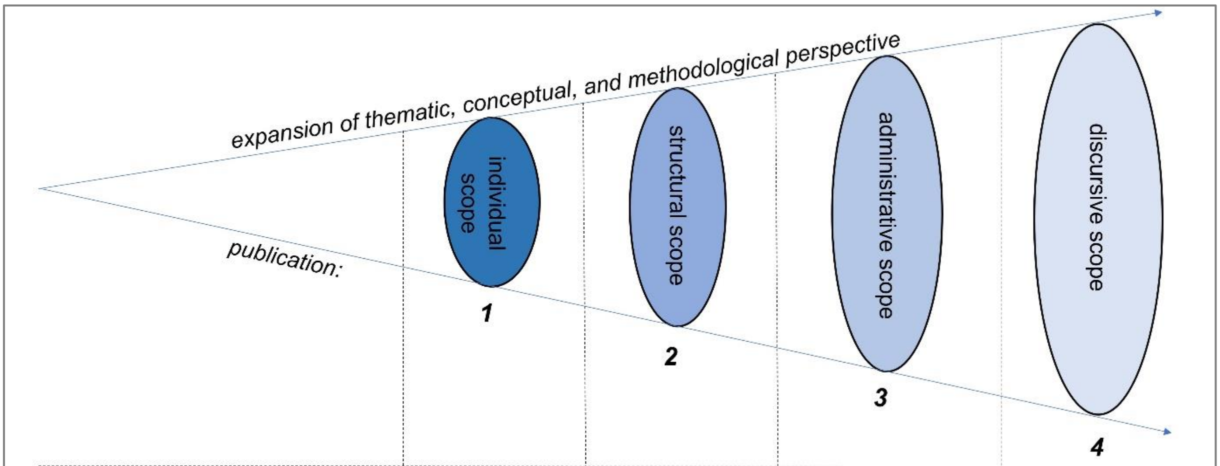
These general amibitions translate into a set of specific research questions for this study:

- How does the implementation of Bt cotton technology affect the vulnerability of Indian cotton smallholders?
- What structural political economic implications result from these effects on individual households?

- How are the Bt cotton-related refuge policies affected in the process of policy adaption and implementation?
- Which generalizable characteristics do imaginaries and narratives assume within the constitution of imagined futures of bioeconomic actors involved in the field of agricultural biotechnology innovation?

The initial focus of the presented thesis lies on the rural socio-economic implications of Bt cotton technology implementation in the Indian cotton-producing sector. Based on this general focus, I expand the angle of observation throughout the course of the exploratory study as depicted in figure 1. While starting from an individual socio-economic perspective, I widen the range of consideration to structural implications based on approaches of the political economy realm, before addressing administrative entanglements with the earlier-exposed outcomes. Finally, I integrate a discursive perspective in the study as I investigate more abstract and diffuse enmeshments of the Bt technology by drawing on the notion of imagined futures. In accordance with the expansion of the thematic focus, I also adjust the chosen conceptual approaches. Overall, various concepts from classical development geography approaches (e.g., sustainable livelihoods, vulnerability) and approaches related to political economy (e.g., accumulation by dispossession, moral economy) to more recent approaches from the research fields of Science and Technology Studies (STS) or economic sociology (e.g., policy assemblages, imagined futures) are applied and combined with considerations of agri-food geographies.

As also shown in figure 1, I further pursue this dilation of perspective in regard to methodological approaches. While I first draw on qualitative, guided interviews with farmers and other actors involved in cotton production in order to analyze individual socio-economic outcomes of the technology adoption, I revert to a quantitative survey of Bt cultivating households in the three highest-ranking cotton-producing districts of Telangana to expose structural political economic effects of the implementation of Bt technology. In order to unravel the administrative entanglements with these recent developments in the Indian cotton sector, I resort to document analysis and re-embed my findings into the rural context of cotton production by means of a multivariate cluster analysis of the surveyed Telangana cotton peasantry. For the purpose of revealing more diffuse implications of the technology's implementation on a discursive level, I employ expert interviews conducted with top ranking entrepreneurs, politicians, and activists involved in Indian biotechnology innovation, and contrast them with bioeconomic innovation actors from Germany.



conceptual approach	vulnerability, sustainable livelihoods	vulnerability, ABD, hegemony	policy assemblages, moral economy	imagined futures
methodological approach	qualitative interviews (n=42)	quantitative survey (n=457)	document analysis, survey (n=457) (cluster analysis)	expert interviews (n=14)
central findings	farmers' vulnerability context changed: PBW returned, malfunctioning of Bt technology	socio-biological obsolescence of Bt technology causes ABD that reproduces prevalent hegemonic structures	policy mobility accompanied by mistranslations of Bt refuge policies; entrepreneurial mindset of farmers neglected by state authorities	uncertainties of economic actors bridged by fixed imaginaries and dynamic narratives (rejection, stabilization, adaptation of narratives)

Figure 1: Outline of research design (own sketch)

This research is part of the project *"Politics of knowledge and non-knowledge: agricultural biotechnology in India"*, supported by the German Research Foundation (DFG; KE1983/3-1), led by Dr. Markus Keck in the function of principal investigator (PI). I conducted this research in the position as a doctoral researcher. The project initially focused on mapping the politicization of the controversy around agricultural biotechnology (cf. Knobloch and Keck 2018). In accordance with the project's overall focus on knowledge and non-knowledge connected to agricultural biotechnology in India, the subordinated research presented here first intended to address general agricultural decision-making processes in Bt cotton-producing households. I was, however, urged to readjust my research focus due to the recent re-occurrences of the target pest of Bt technology, which altered the situation for Bt cotton smallholders and other actors involved in the neoliberal rural Indian nexus of the Bt cotton sector. As this new development required a re-evalutation, I thus instead focalized on hitherto insufficiently investigated questions on rural socioeconomy as well as risk and vulnerability-related implications arising from the implementation of GE cotton and the related recent developments of target pest re-occurrences for Indian smallholders. This shift in focus was inductively evoked by our interview partners and was facilitated by the exploratory research design implemented in this study.

1.2 Structure of the thesis

These research questions and aims of the thesis result in the structure outlined below. Aiming to provide orientation to the reader, I first present the context of Bt cotton production in India in chapter 2. In the same chapter, I further outline the current state of the controversy in the scientific literature and specify my contribution to this debate. In chapter 3, I give an overview of the concepts I used to examine hitherto marginalized perspectives of subaltern actors on rural socioeconomy and on risk and vulnerability-related implications resulting from the adoption of Bt cotton for Indian smallholders. Following an exploratory research approach, I expand my focus throughout the research and approach the debate via a pluralized conceptualization, applying classical action-oriented concepts of development studies, e.g., vulnerability; concepts from the realm of political economy, e.g., accumulation by dispossession; and more recent concepts from STS, e.g., policy assemblages, as well as imagined futures from the field of economic sociology. Chapter 4 then gives a detailed overview of the qualitative and quantitative research methods I applied for both data acquisition and data analysis. It also presents the study area and explains the procedure for selecting the sampling sites.

In chapters 5, 6, 7, and 8, I then present in-depth analyses of (1) the individual vulnerability context of Bt cotton farming households, (2) the resulting structural political economic implications, (3) the administrative assemblage of Bt cotton policy mobilities, and (4) the discursive embedding in considerations of economic sociology related to the constitution of the imagined futures of biotechnological innovation actors. In chapter 5, I hence investigate the socio-economic impacts of the technology implementation on livelihoods of Bt cotton farming households and their responses to the re-occurrence of the target insect using qualitative guided interviews. In chapter 6, I expand my focus to the structural implications of the farmers' altered vulnerability context by connecting the results of a representative survey conducted in Telangana to political economic considerations and Gramscian approaches to hegemony. In chapter 7, I follow the mobilities of Bt cotton-related policies in their administrative assemblage by means of a document analysis and the results of a multivariate cluster analysis of the Telangana cotton peasantry, and link my findings to moral economic considerations. In chapter 8, I outline the imagined futures of actors involved in biotechnology innovation by retracing their empirically accessible narratives and imaginaries involved in their future trajectories of agricultural GE innovations by drawing on expert interviews.

In chapter 9, I then synthesize my central empirical findings and contributions to the field of agri-food geographies. I further outline my conceptual and methodological contributions to the geographic discipline. The final chapter 10 concludes the findings of this thesis and presents the need for research, as well as recommendations for action for state authorities and other policy-making actors involved in the nexus of Indian Bt cotton production.

2 Empirical setting

With the aim of providing orientation and background information to the reader, this chapter maps out the basics of cotton production in India[2]. It also explains the general functioning of Bt cotton technology, which is important for contextualizing the ongoing debate surrounding the adoption of the technology. The contesting sides of the prevailing controversy will be outlined in more detail in this chapter as well. Finally, from this review of the current state of the scientific literature, I derive the contribution of my research.

2.1 Cotton production in India

Cotton (*Gossypium sps*) occupies a predominant position amongst cash crops in India (Kaviraju et al. 2018; USDA 2020). With a production of 6.1 million metric tons for the season of 2020/21, India is currently the world's second largest cotton producer, accounting for 23% of global cotton production (USDA 2022a, 2022b). Before the COVID-19 pandemic, the country was in fact the leading cotton producer worldwide, but has now again been surpassed by China with a production of 6.4 million metric tonnes (USDA 2022b). As the third-ranking USA is clearly behind with a production of 3.2 million metric tonnes, India still maintains a significant position in the global production of the fiber crop (USDA 2022b). While India used to be a net importer of cotton in 2002, it emerged as an exporter of the crop by 2008-09 (Kurmanath 2018a). Now, India is the third biggest cotton exporter worldwide, with annual exports of around 1.3 million metric tonnes (season 2020/21) (USDA 2022b).

This comparison of the numbers in global cotton production plausibly illustrates the importance of cotton cultivation and adjacent industries for the Indian economy. Overall, cotton farming provides livelihoods and income for about 10 million rural households in the country, of which 7.5 million are smallholder households that own less than 10 to 15 acres and grow an average of 3 to 4 acres of cotton (Subramanian and Qaim 2010; Kathage and Qaim 2012; ISAAA 2017; Altenbuchner et al. 2018). Choudhary and Gaur (2010) estimate that in India alone, the lives of around 60 million people are impacted by the cotton crop.

In India, cotton is cultivated under irrigated as well as rainfed conditions by the major cotton-producing states Punjab, Haryana, Rajasthan, Madhya Pradesh, Gujarat, Maharashtra, Andhra Pradesh, Karnataka, Telangana[3], Tamil Nadu, and Orissa (Odisha) (Choudhary and Gaur 2010, 2015; Kaviraju et al. 2018). These states are grouped into three different zones of

[2] Parts of this chapter have been adapted from my unpublished master's thesis (Najork, K. 2019. The Impact of Bt Cotton on Peasant Livelihoods in Karimnagar District in Telangana, India).

[3] Telangana officially became the 29th state of India in 2014. The data going back prior to that date refer to Andhra Pradesh, since, until its foundation, it belonged to the state of Andhra Pradesh (cf. Mohan 2014).

cotton production: The northern zone (Punjab, Haryana, and Rajasthan), the central zone (Maharashtra, Madhya Pradesh, Gujarat, and Orissa (Odisha)), and the southern zone (Andhra Pradesh, Telangana, Karnataka, and Tamil Nadu) (ISAAA 2009; Choudhary and Gaur 2010; Arora and Bansal 2012). As shown in figure 2, of these three zones, only the northern zone is irrigated whereas both the central as well as the southern cotton-cultivating zones are predominantly rainfed (Choudhary and Gaur 2010, 2015; ISAAA 2009). Congruously, approximately 65% of India's cotton production are grown on non-irrigated land and 35% on irrigated land (ISAAA 2009; Choudhary and Gaur 2010, 2015; Gaurav and Mishra 2012; Kaviraju et al. 2018). As cotton is a *kharif*[4] crop and is hence grown in the monsoonal period, it is usually sown in June and harvested in the time from October to January (ISAAA 2017; Kurmanath 2018b). As more than 90% of the country's cotton acreage is cropped with the GE variant of the plant, it seems impossible to analyze cotton production in India without taking agricultural biotechnology into consideration (ISAAA 2018).

[4] Depending on the species planted, crops are grown in two different seasons in India. The *kharif* season is the monsoon season, which begins in June. It thus approximately refers to the autumn season. The *rabi* season usually begins after the *kharif* crops are harvested and refers to the winter season.

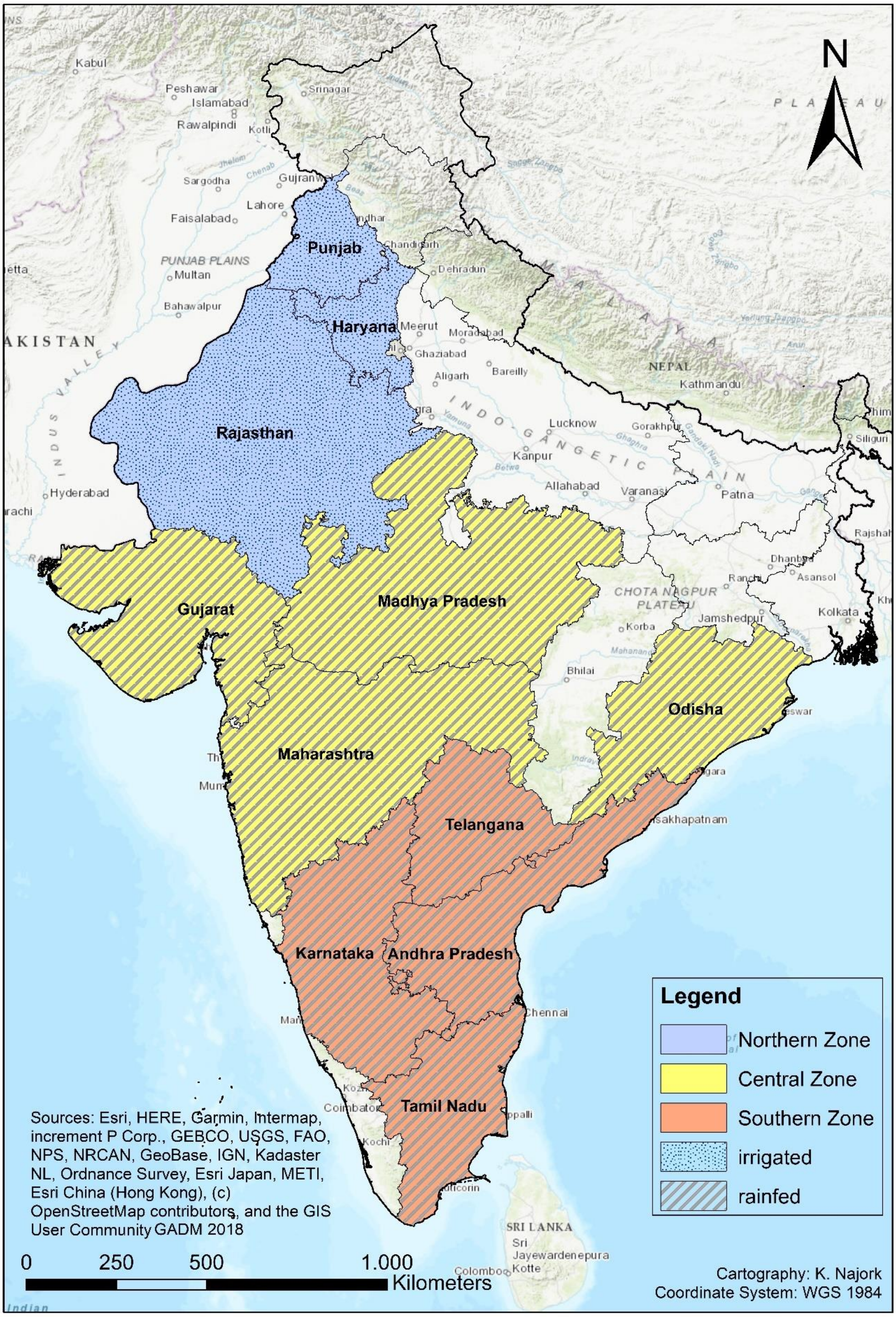


Figure 2: Zones of Indian cotton production

2.2 Neoliberal reforms in the Indian cotton sector

The cultivation of cotton species has a long tradition in India. For the most part of their ancient agrarian history, Indian farmers were mainly growing indigenous ‘desi’ cotton varieties of *Gossypium arboreum* (Prasad 1999; Kranthi and Stone 2020). In the 1990s, however, the Indian agrarian sector was restructured subsequent to broad-based neoliberal economic reforms, which included the easing of state regulations and the commercialization of seed production, and resultingly a shift in the role of farmers toward a more capitalist rationality (Glover 2007; Flachs 2019a). These reforms went along with the spread of more input-intensive cotton hybrids originating from American (New World) varieties (*Gossypium hirsutum*) (Prasad 1999; Flachs 2019a; Kranthi and Stone 2020). Moreover, the reforms provided new opportunities for large and foreign-owned companies in Indian agri-input markets, so that during the 1990s, the overall private sector share of the Indian commercial seed market grew to 60% and some companies recorded annual growth rates of more than 20% (Glover 2007).

Parallel to this development in the Indian agricultural market, the Bt cotton technology was developed. As one of the first GE crops, Bt cotton was authorized for commercialization and entered the global seed market (Qaim et al. 2008). The pioneering country to authorize the commercial cultivation of Bt crops was the US, where Bt cotton was approved in 1995 (Qaim et al. 2008; ISAAA 2022). After this, the adoption of transgenic crops spread further and reached other countries, dispersing also among developing countries, not least because of the promised agro-economic advantages such as yield increases and reductions in pesticide use (Dev and Rao 2007; Smale 2016). Due to these expected benefits, Bt technology was also released in India as the first GE crop technology to be legalized in the country (Naik et al. 2005; Qaim et al. 2006).

2.2.1 Bt cotton technology

Altogether 162 species of insect pests harm the cotton crop at different stages of growth (Kaviraju et al. 2018). In India, these are mainly two species: Lepidopteran caterpillars, evolving into moths after having fed on the cotton bolls (hence called ‘bollworms’), and Hemipteran sap-sucking pests (Kranthi and Stone 2020). In respect to the Indian cotton cultivation, important examples of the latter are cotton aphids (*Aphis gossypii*), whiteflies (*Bemisia tabaci*), the leaf hopper (*Amrasca devastans*), and jassids (*Amrasca bigutulla*), a subspecies of the leaf hopper (Hallad et al. 2014; Kranthi and Stone 2020). While these secondary pests[5] are not negligible, the major limiting factor in the production of cotton regarding damage caused by insect pests are Lepidopterans, particularly the most loss inducing 'bollworm complex'. This complex includes the spotted bollworm (*Erias sp.*) as well as India's two most detrimental Lepidopterans, the American bollworm (ABW; *Helicoverpa armigera*, Hübner), and the pink bollworm (PBW; *Pectinophora gossypiella*, Saunders) (Naik et al. 2005; Choudhary and Gaur 2010, 2015; Kathage and Qaim 2012; Kaviraju et al. 2018; Kranthi and Stone 2020).

In order to tackle the problem of agricultural losses caused by Lepidopterans, Bt cotton technology was developed. As opposed to conventional pesticides, this GE biotechnology operates at seed level dissemination and in this way evokes a built-in pest resistance in the host plant (Kaviraju et al. 2018). To achieve this built-in protection against the targeted group of insect pests, the target plant is equipped with the relevant gene (or genes) that is isolated from other organisms unrelated to the target plant, such as bacteria, by means of genetic engineering and is subsequently introduced into the target plant (Choudhary and Gaur 2008, p. 15).

One of the most widely adopted examples of such GE biotechnologies in agricultural crops is the *Bacillus thuringiensis* (Bt) technology, which is used, for example, in Bt cotton, Bt maize, Bt eggplant, and Bt potato (Qaim et al. 2008; Kathage and Qaim 2012). The natural and ubiquitous Bt bacterium is a gram positive and spore forming soil bacterium, which contains genes that encode parasporal crystalline (*Cry*) proteins, which are highly toxic to certain insect species when ingested (Herring and Rao 2012; Ramaswami et al. 2012; Altenbuchner et al. 2018; Kaviraju et al. 2018; Kukanur et al. 2018). While being harmless to all non-target insects, these endotoxins act specifically on species of the Coleopteran (beetle species) and Lepidopteran (butterfly species) pests (Thirtle et al. 2003; Qaim et al. 2008). They are hence lethal to Lepidopterans including bollworm insect species, such as the ABW and the PBW (Thirtle et al. 2003; Khan et al. 2018; Kranthi and Stone 2020). Once the relevant genes are induced into the target plant, they are reproduced by the now transgenic crop which then contains the according endotoxins (Naik et al. 2005; Kukanur et al. 2018).

Until now, three generations of Bt cotton have been developed, of which the first two are authorized in India (Choudhary and Gaur 2015; Tabashnik and Carrière 2019). For the first generation of Bt cotton (Bollgard I, Bt I), the *Cry* gene isolated from the Bt bacterium and then induced into the host plant is called 'Cry1Ac'. While the first Bt cotton generation contains only one gene, its double gene successor (Bollgard II, Bt II) contains two genes that are relevant for the built-in protection. In addition to the first 'Cry1Ac' gene, the second generation of Bt cotton also expresses the 'Cry2Ab' gene (Kukanur et al. 2018; Kranthi and Stone 2020). In

[5] As opposed to major pests, secondary pests account only for minor or sporadic crop damage (Wang et al. 2008).

India, these genes are almost exclusively induced into hybrid seeds, whereas in other Bt cotton growing states, conventional cotton seed varieties are generally used for the induction of Bt traits (Tabashnik and Carrière 2019).

Even though the third generation (Bollgard III, Bt III) has not (yet) been commercialized in India, it will be briefly addressed at this point for the sake of completeness. It differs from the first two Bt cotton generations in that it not only aims to defang major cotton target pests through a built-in pest resistance, but also includes a trait for herbicide-tolerance (HT-Bt cotton). In addition to the *Cry*-proteins from the Bt bacterium, this hybrid contains a supplementary vegetative insecticidal protein (*Vip*), the 'Vip3Aa' (Tabashnik and Carrière 2017). The effect of this third additional protein on bollworm species, however, remains contested among scholars. While some claim that the additional protein provides a more diversified crop protection against Lepidopteran pests and thus prolongs the durability of trait-induced crop technology (Bayer 2022), leading entomologists in the field argue that 'Vip3Aa' "is not highly effective against pink bollworm" (Tabashnik and Carrière 2019, p. 2519). Although this technology is not approved in India, its unauthorized cultivation by farmers has recently sparked a major controversy in the country (ISAAA 2017, p. 29).

2.2.2 Refuge crops

Insect resistance management (IRM) strategies are employed by most Bt cotton-producing countries. These strategies aim to prolong the built-in resistance of the crop technology by delaying the evolution of insect resistance to Bt cotton. Since the beginning of the implementation of the technology and still today, the primary IRM strategy adopted among producing countries worldwide is the planting of so-called 'refuge crops' (also called 'refugia' or 'trap crops') (Tabashnik and Carrière 2019).

These refuge crops are other non-Bt crops that are usually planted around or near the Bt cotton field in order to reduce the evolutionary pressure on target pests (Kranthi et al. 2017; Mohan 2018, 2020; Tabashnik et al. 2021). The principle is that the target insects feed on the non-GE crops surrounding the fields, and therefore allow reproduction of the target pest without evolutionary pressure imposed by the Bt toxin (Jayan 2018; Mohan 2018; Tabashnik and Carrière 2019). The non-Bt crops thus serve to produce larvae that are susceptible to the Bt toxin in order to mate with the rare homozygous Bt-resistant moths emanating from the Bt cotton crops (Mohan 2018, 2020; Tabashnik et al. 2021). Based on the premise of population genetic theory that the inheritance of resistance to Bt cotton is recessive, as is the case for Lepidopterans like pink bollworm moths, two parental lines then bear heterozygous offspring that is again susceptible to the endotoxins (Gould 2000; Mohan 2018, 2020; Tabashnik et al. 2021).

For this purpose, seed producers attach a separate seed bag containing only non-Bt hybrids (120g) to each sold bag of Bt hybrids (450g) (Kranthi 2015; Kranthi et al. 2017; Mohan 2018). In India, the ratio prescribed for this measure is 95:5 (Bt:non-Bt) (Genetic Engineering Approval Committee (GEAC) 2011; Kranthi 2015; Kranthi et al. 2017; Mohan 2018).
Overall, however, the success of this preventive pest management strategy strongly depends on the actual implementation in the field (ISAAA 2018; Tabashnik and Carrière 2019; Tabashnik et al. 2021). As cotton farmers in India often renounce compliance, since this entails economic sacrifices for them, the ISAAA (2017, p. 29) accuses farmers of mismanaging the technology and argues that the technology's efficacy could have been prolonged if they had followed instructions. Resultingly, Indian authorities recently endorsed the implementation of 'refuge-in-bag' (RIB)[6] policies (Mohan and Sadananda 2019; Mohan 2020; Kumar et al. 2021). In contrast to the 'structured refuge' policy, in which the non-Bt and Bt seeds are separated in the seed package, with RIB the mandated 5% of non-Bt cotton seeds are blended with the Bt seeds (475g) (Kranthi et al. 2017; Mohan and Sadananda 2019; Mohan 2020; Kumar et al. 2021). Refusing farmers the choice of (refraining from) planting a refuge, this method is sometimes entitled 'compliance-assured' (Kranthi et al. 2017; Mohan and Sadananda 2019; Mohan 2020).

2.3 The commercialization of Bt cotton in India

The fact that cotton was the first crop in India to undergo field trials for Bt technology does not come as a surprise, given the historical as well as current significance of the fiber crop for Indian agriculture (Sadashivappa and Qaim 2009). The long-lasting and still prevailing position of cotton amongst cash crops in the country is exemplified by India's current status as the world's second largest producer (Food and Agriculture Organization (FAO) 2022). After the field trial testings, Bt cotton therefore became the first GE crop to be authorized and commercially distributed in India (Qaim et al. 2006).
The chronology of Bt cotton commercialization in India began in 1995 with the import of 100 grams of the transgenic Cocker-321 variety of cotton seed cultivated by Monsanto in the US (Glover 2007; Kiresur and Ichangi 2011; Choudhary et al. 2014). The import of the seeds that contained the relevant Cry1Ac gene to India was permitted for research purposes by the Department of Biotechnology (DBT) under the Indian Government's Ministry of Science and Technology (Kiresur and Ichangi 2011). Before Bt seeds had been officially authorized for commercialization, however, unapproved transgenic seedlings are known to have been grown in parts of the states of Gujarat, Maharashtra, Madhya Pradesh, Andhra Pradesh, and Karnataka. Illegal Bt cotton seeds, such as the unlicensed Bt hybrid NB-151 from the Indian

[6] Sometimes also referred to as ‚built-in-refuge' (BIR) (Kumar et al. 2021).

seed company *NavBharat Seeds,* were cultivated on more than 10,000 acres in 2001 in the state of Gujarat alone (Scoones 2005; Sadashivappa and Qaim 2009; Glover 2007, 2010; Ramaswami et al. 2012).

Subsequent to this illegal cultivation of the GE crop, in March 2002, the GEAC[7], under the Ministry of Environment and Forestry (MoEF), officially decided in favor of the release of Bt cotton seeds for commercial cultivation in India (Glover 2010; Ramaswami et al. 2012; Kaviraju et al. 2018; Yadav et al. 2018). Thus, during the crop season of 2002-03, the first generation of Bt cotton (Bollgard I, Bt I) containing the Cry1Ac gene was approved by the national regulatory authorities.

This first authorization included three hybrids, MECH-12, MECH-162, and MECH-184, which contained the inserted Cry1Ac gene and were based on Monsanto's Bt technology event MON-531 (Naik et al. 2005; ISAAA 2009; Kiresur and Ichangi 2011; Kathage and Qaim 2012; Kukanur et al. 2018; Yadav et al. 2018). A collaboration was formed with the private *Maharashtra Hybrid Seed Company* (*Mahyco*) to start a joint venture of the two companies; in 1998, *Mahyco Monsanto Biotech Limited* (*MMBL*) was established (Ramamurthy 2000; Scoones 2005; Qaim et al. 2006; Glover 2007; Ramaswami et al. 2012). In the end, this joint venture of MMBL succeeded, as outlined above, with the approval of the three Bt cotton hybrids in 2002. Firstly, the three Bt hybrids were released in the central and southern zones of cotton production in India for a period of three years before an approval for the northern Indian zone of cotton production followed in 2005 (Ramaswami et al. 2012; Kranthi and Stone 2020). In the subsequent years, several other Bt cotton hybrids were approved for cultivation (cf. Table 1). In the ensuing period, MMBL sublicensed their authority-approved Bt cotton technology to other Indian seed companies, which allowed an incorporation of the technology into various Indian cotton hybrids and thus accelerated the spread of Bt cotton in the country (Sadashivappa and Qaim 2009). A surge of Bt cotton adoption was the consequence (Kranthi and Stone 2020) (cf. fig. 4, 5).

During the years 2004 and 2005, 17 additional Bt hybrids were developed by three other Indian seed companies (e.g., *Rasi Seeds*) after they had obtained the sublicense for the MMBL Bollgard I technology, and were then authorized for commercialization by the GEAC (Kathage and Qaim 2012). Thus, as is depicted in Table 1, the 2000s coined the beginning of an exponential growth of the commercial authorization of several other Bollgard I hybrids (Choudhary and Gaur 2010, p. 13). As a result, conventional brands were displaced from the seed shop shelves in many areas. This development of rapid Bt hybrid diffusion in India was therefore accompanied by the replacement of cotton seed varieties with hybrid seeds (Kranthi

[7] The Genetic Engineering Approval Committee was renamed Genetic Engineering Appraisal Committee in 2010. In this context, the GEAC was downgraded to a national appraisal committee without executive legal functions and was hence deprived of the mandate to authorize transgenic organisms (Choudhary et al. 2014; Herring 2015).

and Stone 2020). This is interesting inasmuch as, until today, India remains the only country that relies on hybrid seed breeding for Bt-trait insertion instead of conventional seed varieties (Tabashnik and Carrière 2019).

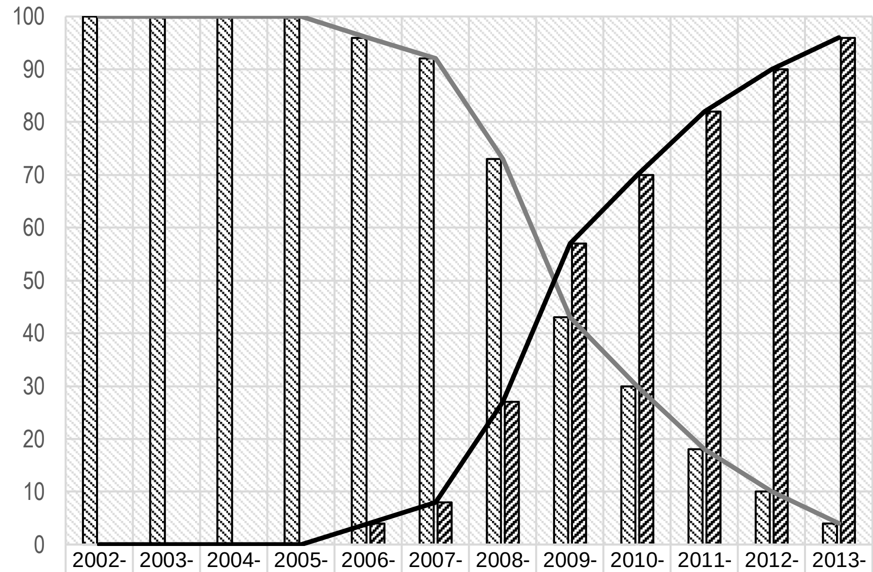
While these years marked the introduction and initial diffusion of the first Bt cotton generation, they were the starting point for the approval and release of further Bt generations, too (cf. Table 1). In 2006, three new Bt events (MON 15985, Event-1, GFM Event) were approved by the GEAC, including the first multiple Bt cotton event (MON 15985) (ISAAA 2009; Choudhary and Gaur 2010; Kathage and Qaim 2012). As the resulting hybrids contained two induced genes of the Bt bacterium (Cry1Ac and Cry2Ab), this heralded the onset of the next generation of Bt cotton (Bollgard II, Bt II) (ISAAA 2009; Choudhary and Gaur 2015; Kukanur et al. 2018). In contrast to these above-mentioned Bt events that were all incorporated in cotton hybrids, in 2008, the GEAC authorized a fifth Bt event, which was induced into an indigenous cotton variety (*Bikaneri Narma*) this time (ISAAA 2009; Choudhary and Gaur 2010). While *Bikaneri Narma* was thus the first approved conventional Bt cotton variety in India, until today, Bt cotton hybrids are prevalent in the country (Tabshnik and Carrière 2019).

By 2014, a total of six events and 1167 hybrids had been approved for planting, most of which were hybrids of the second Bt generation (Bollgard II) (Choudhary and Gaur 2015: 11-12). The number of authorized hybrids has hence experienced an exponential growth since the legalization of the first Bt cotton hybrids in India (cf. Table 1).

Table 1: Number of events, hybrids, and selling companies of Bt cotton (Choudhary and Gaur 2015: 11-12)

Year	No. of Bt cotton events	No. of Bt cotton hybrids	No. of seed companies selling Bt cotton
2002-03	1	3	1
2003-04	1	3	1
2004-05	1	4	1
2005-06	1	30	3
2006-07	4	62	15
2007-08	4	131	24
2008-09	5	274	30
2009-10	6	522	35
2010-11	6	780	35
2011-12	6	884	40
2012-13	6	1097	44
2013-14	6	1167	45

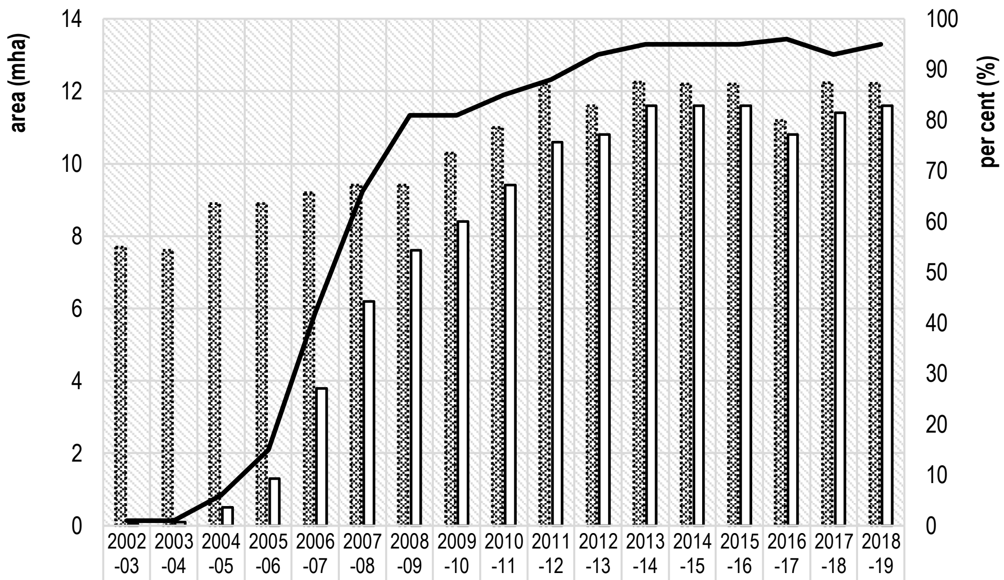
Congruent to the increasing number of dual gene hybrids, the second generation of Bt crops has now almost entirely replaced the single gene seeds in the cotton production of the country (cf. fig. 3; Hallad et al. 2014; Choudhary and Gaur 2015; ISAAA 2016). As is depicted in figure 3, 2009 marked the first year with more multiple gene Bt cotton crops (57%) than its single gene equivalent (43%) (Choudhary and Gaur 2010, 2015). In 2014, the adoption rate of single gene Bt cotton in India finally accounted for less than 5%, whereas the adoption rate of double gene Bt cotton had accumulated to 96% (cf. fig 3; Choudhary and Gaur 2010, 2015).



	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14
% of single gene Bt cotton	100	100	100	100	96	92	73	43	30	18	10	4
% of double gene Bt cotton	0	0	0	0	4	8	27	57	70	82	90	96
% of single gene Bt cotton	100	100	100	100	96	92	73	43	30	18	10	4
% of double gene Bt cotton	0	0	0	0	4	8	27	57	70	82	90	96

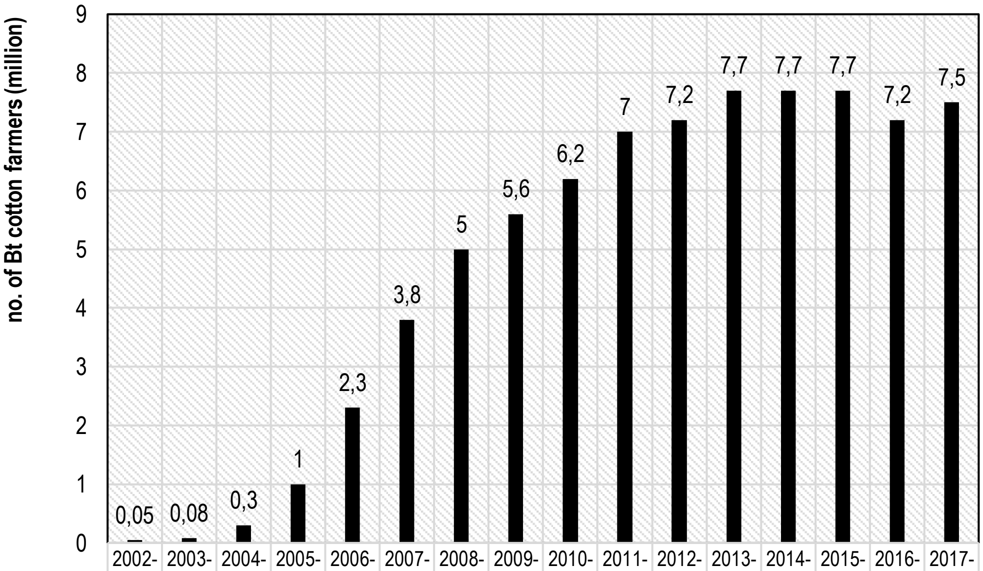
Figure 3: Share of single and double gene Bt cotton (own sketch; cf. Choudhary and Gaur 2010, 2015)

Since Bt cotton was approved in India, the area under the GE technology has drastically increased throughout the country (Choudhary and Gaur 2015; ISAAA 2017). Accordingly, as figure 4 shows, throughout the last decade, the share of the Bt trait-induced crop has constantly remained higher than 90% (cf. fig 4). Today, an estimated 95% of the cotton area are cropped with the Bt plants, which emphasizes the crucial role the technology has taken for the Indian cotton sector (ISAAA 2017, 2018). Figure 5 then portrays that in alignment with the increase of areal Bt cotton cropping, the number of adopting farmers has increased accordingly (cf. fig. 5; ISAAA 2017, 2018).



	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19
Total cotton area (mha)	7,7	7,6	8,9	8,9	9,2	9,4	9,4	10,3	11	12,2	11,6	12,25	12,2	12,2	11,2	12,24	12,21
Bt cotton area (mha)	0,05	0,1	0,5	1,3	3,8	6,2	7,6	8,4	9,4	10,6	10,8	11,6	11,6	11,6	10,8	11,4	11,6
Bt cotton area (%)	1	1	6	15	42	66	81	81	85	88	93	95	95	95	96	93	95

Figure 4: Total cotton area and total Bt cotton area and Bt cotton share of total cotton area (own sketch; cf. Choudhary and Gaur 2015; ISAAA 2017 2018)



	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15*	2015-16	2016-17	2017-18
no. of Bt cotton farmers (million)	0,05	0,08	0,3	1	2,3	3,8	5	5,6	6,2	7	7,2	7,7	7,7	7,7	7,2	7,5

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Figure 5: Number of Bt cotton farmers (own sketch; cf. ISAAA 2017, 2018)

2.4 Cotton pest dynamics and the re-emergence of pink bollworm

For a contextualization of the effects of Bt cotton technology in India, historical pest dynamics have to be taken into account. Prior to the introduction of Bt technology, the major cotton-damaging pest in the country was the American bollworm (ABW; *Helicoverpa armigera*, Hübner). The pest surged when insecticide-intensive *hirsutum* (American cotton varieties) hybrids were introduced to the cotton sector in the 1980s (cf. chapter 2.2) (Prasad 1999; Kranthi 2016; Kranthi and Stone 2020). Aiming to defang the former major pests, the pink bollworm (PBW; *Pectinophora gossypiella*, Saunders) and the cotton leafworm (*Spodoptera litura*), the widespread use of pyrethroids, a synthetic type of insecticides, led to the surge of the ABW, a pest that was resistant to the common insecticides of the time (Kranthi 2016; Kranthi and Stone 2020). Troubled by the worsening pest problems, the introduction of Bt cotton meant a hope for improvement through technological advancement for the Indian cotton sector, and in fact, the adoption of the new seeds was paralleled by a decrease in the use of Lepidoptera-targeting pesticides and contributed noticeably to controlling both ABW and PBW in the early years of Bt diffusion (Kranthi and Stone 2020).

However, in 2009, a few years after the authorization of the technology, resistances of PBW populations to the *Cry* protein encoded in the first generation of Bt cotton (Cry1Ac) were reported for the Indian state of Gujarat (Haribabu 2014; Mohan et al. 2016; Naik et al. 2018). In contrast to the monophagous PBW, the ABW has not developed resistance to *Cry* toxins as it is a polyphagous pest that does not exclusively feed on cotton. Therefore, when confronted with Bt toxins in Bt cotton plants, it faces a lower evolutionary pressure than the monophagous PBW, which feeds exclusively on cotton (Wan et al. 2017; Tabashnik and Carrière 2019; Wang et al. 2019). The PBW pest outbreaks were then controlled by means of the rapidly diffusing second generation of Bt cotton technology (cf. fig. 3), which promised a more diversified pest control than its predecessor due to its expression of two different *Cry* proteins (Cry1Ac and Cry2Ab) (Naik et al. 2018; Fand et al. 2019).

However, in the *kharif* season of 2015 and after, high levels of PBW infestation were reported for cotton fields cultivated with this second, dual-gene-induced Bt cotton generation in the Indian states of Gujarat, Madhya Pradesh, Maharashtra, Karnataka, Andhra Pradesh, and Telangana (Mohan 2017; Fand et al. 2019). For central and southern Indian cotton-producing states, progressive increases in the survival rate[8] of PBW larvae in cultivated Bt II (F1)[9] hybrid

[8] In the study published by Naik et al. (2018), the survival rate was measured by the number of infested green bolls of Bt II cotton hybrids from 2010-2017. Bolls were dissected and examined for holes, frass, and surviving larvae.

[9] Hybrid seed production aims to produce seeds that express a higher vigor (e.g., higher yield or size) than regularly bred seeds due to the “heterosis effect” of hybrid breeding techniques. This effect is

varieties were reported (Mohan 2017; Naik et al. 2018; Fand et al. 2019). This is interpreted as an indicator that the larvae of PBW have developed a resistance against the endotoxins produced in the cotton plants (Mohan 2017; Naik et al. 2018; Fand et al. 2019).
In central and southern Indian states, the percentage of live larvae increased from zero in 2013 to 64.4% in central India and 72.5% in southern India in 2017 (Naik et al. 2018, p. 2547). As a result, in 2017, the concentration of live larvae found in Bt II cotton bolls was almost as high as in non-Bt cotton bolls with 78.79% in central India and 75.74% in southern India (ibid.). Parallel to this, the median concentration of Cry2Ab toxins lethal for PBW larvae (LC_{50})[10] increased in southern India from 0.004 µg mL^{-1} in 2013 to 4.71 µg mL^{-1} in 2017, and within the same time span in central India from 0.018 µg mL^{-1} to 14.458 µg mL^{-1} (Naik et al. 2018, p. 2547, 2553). Congruent to this development, the resistance ratio (RR)[11] of PBW larvae to Cry2Ab toxins increased from a mean of 1.0 in 2013 to a mean of 1570.0 in southern India in 2017, and from a mean of 6.1 to a mean of 4818.8 in central India during the same time span[12] (Naik et al. 2018, p. 2553). Altogether, these studies have to be interpreted as clear alarm signals that, after its hiatus of almost two decades, PBW has returned in the cotton belt of central and southern India (Kranthi 2015; Mohan and Sadananda 2019; Tabashnik and Carrière 2019). Estimated yield losses related to this increase in PBW infestation, for example, go up to 30% per farming household for the state of Maharashtra (Fand et al. 2019, p. 313).

2.5 Outlining the Bt cotton controversy

The authorization of Bt cotton in India in 2002 was accompanied by a “flurry of field research on farm-level impacts” (Kranthi and Stone 2020, p. 188). While the pace of publications has decelerated since the 2010s, scientific and popular interest in the case have not only persisted, as the risks and benefits of the crop technology have remained controversial since its introduction, but have indeed been reignited after the recent re-occurrences of the pink bollworm (Qaim 2003; Stone 2011; Kathage and Qaim 2012; Choudhary and Gaur 2015;

achieved by crossing previously inbred parental lines which then generate a filial generation (F1) which expresses the desired properties. The F2-generation is the filial generation emerging from the F1-generation. As the relevant genome decays in the following generations, their properties are considered unreliable.

[10] LC_{50} values indicate the concentration of toxin needed to kill 50% of the examined larvae (Naik et al. 2018).

[11] The RR indicates a reference figure that is generated by the division of the LC_{50} values of the insect’s field strain by the LC_{50} values of a reference susceptible strain of the insect (Naik et al. 2018).

[12] Northern Indian states, on the contrary, were not nearly as severely affected by this development: Here, the percentage of live larvae found in Bt II cotton bolls remained at zero throughout the entire measurement period; the LC_{50} values for Cry2Ab remained low at 0.0007 µg mL^{-1} in 2013 and 0.021 µg mL^{-1} in 2017, respectively; and RR values merely increased from a mean of 2.2 (range 1-3) to 7.0 (range 4-12), again from 2013 to 2017 (Naik et al. 2018, p. 2547, 2553).

Gutierrez et al. 2015; Kranthi 2015; Veettil et al. 2016; Flachs 2019a; Kranthi and Stone 2020). On the one hand, particularly agro-economic scholars attribute successes in the Indian cotton production of the early 2000s to the technology and therefore declare it an effective tool against the Indian agrarian crisis (Sadashivappa and Qaim 2009; Kathage and Qaim 2012; Veettil et al. 2016). These proclaimed benefits mainly include an increase in yields, the parallel reduction of pesticide use, and resultant improved farmer profits (ibid.). Opposed studies, on the other hand, accredit these positive agro-economic trends in the Indian cotton production to a plethora of factors (Glover 2010; Gutierrez et al. 2015; Kranthi 2016; Flachs 2019a; Kranthi and Stone 2020). Among these multiple variables, they especially underline the significance of the spreading access to irrigation facilities among Indian cotton farmers, as well as increases in the use of hybrids and fertilizers (Kranthi 2016; Kranthi and Stone 2020). Moreover, the high variability of socio-economic effects of the technology on farming households and the inseparability of agricultural technologies with specific local agricultural practices is emphasized by contesting anthropological studies (Stone 2007; Glover 2010; Stone et al. 2014; Stone and Flachs 2017; Flachs and Stone 2018; Flachs 2019a). Accordingly, these scholars refute early agro-economic findings of proclaimed successes of Bt cotton in rural poverty reduction (Glover 2010) and report negative social (erosion of farmers' knowledge) (Stone 2007; Flachs 2019a) and ecological side effects (outbreaks of secondary pests, upcoming resistance to the target pest) (Kranthi 2015, 2016; Gutierrez 2018; Flachs 2019a; Tabashnik and Carrière 2019; Kranthi and Stone 2020).

2.5.1 Yields and profits

Early agro-economic studies that are largely based on pre-2008 data ascribe higher effective cotton yields achieved during that period almost exclusively to the technology (Naik et al. 2005; Kathage and Qaim 2012; Plewis 2014; Choudhary and Gaur 2015; Smale 2016). These early studies found that Bt cotton had "strongly outperformed" its conventional equivalent (Kathage and Qaim 2012, p. 1). In his trailblazing study on Bt cotton field trials, Qaim (2003) found the GE crop's yields to exceed those of its non-Bt counterpart by 80%. Studies investigating yields of non-trial fields that followed shortly thereafter still found yield advantages of 63% (Bennett et al. 2006), respectively 40% (Sadashivappa and Qaim 2009). In a later farm-level study relying on panel data, Kathage and Qaim (2012) analyzed Bt cotton yield trends between 2002-2008 and still proclaimed yield increases of 24%.

These higher effective yields are reported to have led to higher farmer profits and living standards for adopting households (Sadashivappa and Qaim 2009; Kathage and Qaim 2012; Yadav et al. 2018). Significantly higher revenue from Bt cotton was described due to the proclaimed yield increases (Bennett et al. 2006), gains in cotton profits among smallholders of

50% were purported (Kathage and Qaim 2012), and elevated incomes of 44% of adopting households reported (Morse et al. 2007). Consequently, increased household living standards of 18%, as well as increased household consumption was found among Bt adopters (Kathage and Qaim 2012; Yadav et al. 2018). Thus, as most of the adopting farmer households were relatively poor, Kathage and Qaim (2012, p. 3) postulated that “Bt cotton contribute[d] to positive economic and social development”. Bt cotton technology was hence denoted as a pro-poor technology (Sadashivappa and Qaim 2009; Kathage and Qaim 2012; Yadav et al. 2018; see also Glover 2010). In addition, advocating voices within the Bt debate early on designated these benefits as sustainable (Sadashivappa and Qaim 2009).

While most agro-economists proclaimed the findings outlined above as a ‘triumph’ of the GE technology, other scholars allude to selection biases, as early adopters are argued to be an unrepresentative group of high producers, and further call into mind the modesty of annualized yield findings (Kranthi and Stone 2020). As such, Kranthi and Stone (2020) point out that agro-economic findings covering panel data of a period over several years, for example the 24% yield increase found by Kathage and Qaim (2012), were in fact in line with a study by Stone (2011) that found a yield increase of 18% for the years of 2003-2007. They therefore argue that these studies “find common ground” as the annualized yield effects were both in the range of 4-5% – and therefore turned out rather modest (Kranthi and Stone 2020). In addition, cotton yields in India have often been found to oscillate in dependence of weather influences and pest population impacts, thus showing fluctuations of over 10% independent of major technological change (Kranthi and Stone 2020, p. 189; see also Gaurav and Mishra 2012).

In consequence, later studies accredit lower isolated contributions to the positive effects portrayed in recent cotton production figures to Bt technology. Instead, they point to multiple agrarian factors, most prominently the use of hybrid seeds, the expansion of access to irrigation facilities, and increases in fertilizer application to explain yield gains of the early 2000s (Glover 2010; Stone 2011; Gutierrez et al. 2015; Kranthi 2016; Flachs 2019a; Kranthi and Stone 2020). The recent study by Kranthi and Stone (2020) demonstrates this most prominently by outlining the temporal differences between cotton yield surges and the adoption rate of Bt cotton. Exemplarily, they portray the surge in yields for the season of 2003-2004 when Bt seeds “were clearly not adopted on a significant scale” and they explain further that by 2005, when Bt adoption was still only at 15.7%, yields had increased to 90% in comparison to 2002 levels (Kranthi and Stone 2020, p. 192). These discrepancies were found to be even higher on a state level (ibid.). This is in line with prior studies arguing that while yield increases of up to 66% (in Warangal District, Telangana) were found during the early years of Bt authorization (2002-2003), these cannot be accredited to Bt cotton “as only 2 per cent of the sample farmers had adopted the new seeds” (Stone and Flachs 2015, p. 122). According to the two scholars, Bt adoption had actually only surged from 2005 to 2007, since then, however,

yields have not risen and instead stagnated nationally and fallen on some state levels (e.g., Andhra Pradesh) (ibid.).
Instead, the spread of hybrid seeds and with that an increased fertilizer application, and the expansion of access to irrigation facilities, are drawn upon to explain these cotton yield surges (Glover 2010; Stone 2011; Gutierrez et al. 2015; Kranthi 2016; Flachs 2019a; Kranthi and Stone 2020). As in India, the Bt trait was mostly bred into *hirsutum* (American varieties) hybrids instead of pre-Bt commonly used *arboreum* (indigenous) varieties (cf. chapter 2.2), it has to be acknowledged that the spread of both Bt and hybrid technology in India's cotton production proceeded simultaneously and can therefore hardly be separated. In this regard, it needs to be taken into account that hybrids, while being water- and fertilizer-intensive, are also more susceptible to the same, in regard to production improvement, compared to seed varieties (Kranthi and Stone 2020). Thus, the large-scale improvements in the spread of irrigation facilities (irrigated cotton area rose from 44.7% in 2003 to 69.5% in 2011) and the rise in fertilizer usage (fertilizer use on cotton more than doubled from 1.2 metric tonnes in 2006 to 2.7 metric tonnes in 2013) during the 2000s have to be considered when analyzing yield trends (Kranthi and Stone 2020).

2.5.2 Pesticide use

The aspect of pesticide reduction is argued by many to be one of the most significant advantages of Bt technology and is said to be the technology's *"raison d'être"* (Qaim 3003; Subramanian and Qaim 2008; Flachs 2017; Yadav et al. 2018). Sprayings were found to have dropped in the early years of Bt cotton implementation, reportedly by around 60% (Qaim 2003; Stone 2011). Veettil et al. (2016, p. 118) observed lower pesticide use in Bt cotton "[a]cross all toxicity classes over time for both Bt and non-Bt cotton". As, according to Kathage and Qaim (2012, p. 2), an "areawide suppression of bollworm populations" was induced due to the widespread adoption of Bt cotton, substantial reductions of pesticide applications were also found for conventional farmers. In addition to environmental advantages, this reduction in overall pesticide use is reportedly paralleled by further upsides in the form of economic and health-related benefits (Qaim 2003; Kathage and Qaim 2012; Plews 2014; Veettil et al. 2016; Yadav et al. 2018).
Flachs (2017, p. 1) instead argues that despite pesticide reductions, Bt cotton agriculture still remains a "risky profession for farm workers", as chemical pesticides are still over-used by many Bt adopters (cf. Venkata et al. 2017). Social pressures, such as the "need to be seen caring for one's field", are often stated as reasons for the over-application of pesticides on Bt crops (Flachs 2017, p. 2; cf. Stone 2011; Gaurav and Mishra 2012; Maertens 2017). Venkata et al. (2017) thus found that despite dropping pest exposure, Bt cotton was still sprayed with

pesticides. Health-related and environment-related risks therefore remain (ibid.). They further claim that workers reported greater qualitative health problems, such as fatigue or hair loss, or even DNA or chromosomal damage (Venkata et al. 2017). Finally, from a long-term perspective, Flachs (2017, p. 2) purports that a decrease in pesticide usage can only be assigned to the initial phase of Bt cotton introduction and diffusion and claims that by 2010, when Bt technology diffusion was ubiquitous in India, "total insecticide applications had largely returned to their pre-GM levels" (cf. Gutierrez et al. 2015). This is in line with Kranthi and Stone (2020) who, in their long-term study, found that the effects of Bt cotton in regard to lower pesticide use were most positive from 2004-2012 when the technology controlled the ABW and PBW. However, according to the two scholars, the built-in pest control was only maintained for the polyphagous ABW, but not for the monophagous PBW that feeds exclusively on cotton (Wan et al. 2017; Tabashnik and Carrière 2019; Wang et al. 2019; Kranthi and Stone 2020). Resultingly, pesticide use increased again after the resurgence of the latter (Kranthi and Stone 2020). Some scholars see a 'treadmill' in this development, which traps farmers in a loop forcing them to use ever-increasing amounts and/or ever-changing forms of pesticides (Gutierrez et al. 2015; Stone and Flachs 2017; Kranthi and Stone 2020).

2.5.3 Secondary pests

Another aspect related to pesticide usage is the required amount of pesticides associated with secondary pests. Again, contrary opinions within the Bt discourse prevail. While in his field-trial study, Qaim (2003, p. 2117) found "no significant difference in the number of sprays used against sucking pests", later studies found that pesticides devoted to secondary pests, such as sucking pests, had increased over time (Gaurav and Mishra 2012; Stone and Flachs 2015; Kranthi 2016; Kranthi and Stone 2020). Stone and Flachs (2015, p. 123) argue that indeed "India does have a problem with sucking pests that are not targeted by Bt" and Gaurav and Mishra (2012, p. 13) reported pesticide costs of Bt growers to have increased to more than twice that of non-Bt growers on account of sucking pests (2012, p. 13). In their recent long-term study, Kranthi and Stone (2020) argue accordingly that populations of sap-sucking pests and expenditures for pesticides targeting the same had increased after the adoption of Bt cotton. They report that by 2018, Indian cotton farmers were spending 37% more on the respective pesticides than pre-Bt (Kranthi and Stone 2020, p. 194). They outlined that this secondary pest species was particularly thriving on *hirsutum* Bt hybrids, in contrast to pre-Bt *arboreum* cultivars (cf. chapter 2.2) (ibid.). Moreover, aphids and mirids have been reported to be problematic for farmers (Stone 2011; Stone and Flachs 2015). Resultingly, a shift in the pesticide market is reported by some scholars in favour of secondary, as opposed to Lepidopteran pests, indicating a change in the type of pest attacks (Stone 2011; Gaurav and

Mishra 2012; Flachs 2017). This development is reported to have resulted in according outcomes regarding the economic impacts for farmers, environmental impacts, as well as health-related effects (Flachs 2017; Gaurav and Mishra 2012).

2.5.4 Impacts on farmer knowledge

Apart from the agro-economic effects outlined above, social impacts of Bt cotton implementation on Indian cotton farmers are discussed. One aspect that has received increased attention particularly among anthropologists is that of agrarian knowledge loss and *agricultural deskilling* (Stone 2007; Stone et al. 2014; Stone and Flachs 2017; Flachs and Stone 2018). In the process of deskilling, practices of *environmental learning* (i.e., empirical assessment) are superseded by mechanisms of *social learning* (i.e., emulation) (Stone 2007; Stone et al. 2014). This is indicated by short-term seed fads or herding (Stone 2007; Stone et al. 2014). This seed faddism describes patterns of cyclical and temporary seed selection by farmers in groups based on the choice of fashionable seed brands instead of empirical assessment, e.g., in the form of experimentation with seed brands in farmers' own fields (Stone 2007; Stone et al. 2014). Unlike the common agro-economic interpretation in regard to high implementation rates of specific Bt cotton seeds, it is thus argued that the Bt cotton seed fads are not a sign of successful farmer experimentation and management skill, but rather a social phenomenon based on mechanisms of emulation (Stone 2007; Stone et al. 2014). As such, these cyclical fads resembled classic models of successive innovation adoption, but instead of periodicity being introduced from outside the system, here the periodicity is generated by an internal dynamic (Stone et al. 2014). The influences of external parties in relation to processes of agricultural deskilling were also addressed by Stone and Flachs (2017), who introduced the notion of *didactic learning*, whereby external parties instrumentally influence the decision-making process of farmers (cf. Stone 2016). They also claim that these types of learning interventions lead to farmer dependence on increasingly capital-intensive agriculture. Altogether, Stone et al. (2014) present results of long-term panel data showing that herding behavior and deskilling have continued and intensified with the spread of Bt cotton hybrids.

This aligns with the findings of Flachs and Stone (2018), who argue that the quality of farmer knowledge and the degree of seed commodification are inversely related. In their study, they analyzed farmer knowledge in relation to their seeds, located on a spectrum of seed commodification ranging from heirloom vegetable seed varieties over open pollinated hybrids of rice to GE cotton hybrids, and found that the more commodified the seed, the less farmers know about its cultivation (ibid.).

Following these findings of knowledge loss and deskilling contextualized by a neoliberal seed market and paralleled by the increasing influence of external parties in farmers' agricultural decision-making, Flachs (2019b) draws on the conception of "scripts" that farmers followed without further agricultural assessment. According to him, these scripts are "learned and socially mediated mental maps that reflect sets of rules, values, patterns, or expectations in smallholder commercial agriculture" (Flachs 2019b, p. 48). Because these scripts are internalized guidelines for farmers' decision-making process and resulting actions, they follow them without questioning them. In the case of Bt cotton production in Telangana, farmers prevalently follow the script, i.e., the expectation, of *manci digubadi* (good yield), as it serves them to navigate amid the uncertain cotton seed market (ibid). This means that farmers "blindly" plant Bt cotton in the internalized anticipation of a high yield.

2.5.5 Economic risk-increase

Cotton crops in general, and Bt cotton in particular, are furthermore discussed in regard to financial risk for the cultivating farmers. The technology is particularly debated in regard to yield loss potential as increased yields do not result from higher yield potentials of Bt hybrids per se, but are attributed to reduced crop losses as a consequence of pest control through in-built pest protection of Bt crops (Qaim 2003; Kathage and Qaim 2012). From the perspective of risk prevention, this is an important detail, as mere protection from yield losses does not equal yield increment as such because "varieties with Bt gene are as susceptible to all the risks in cotton cultivation that non Bt varieties are" and "any effects beyond protection against specific bollworm […] infestation" are not guaranteed (Gaurav and Mishra 2012, p. 3). Considering that cotton is generally regarded as an unstable and hence risky crop, the high yield variability prevails, or is even higher than with conventional cotton as Gaurav and Mishra (2012) argue (cf. Glover 2010; Gutierrez et a. 2015; Louis 2015; Gutierrez 2018). As fluctuations are especially high in non-irrigated areas (Gutierrez et al. 2015), and as 65% of India's cotton cropped area is rainfed, these increased risks have to be kept in mind for Indian rainfed cotton-producing states like Telangana.

The risks of Bt and conventional cotton production described above are accompanied by the controversially discussed issue of reported higher production costs associated with the Bt crop. During the initial stages of Bt cotton introduction in India, this discussion focused on higher seed costs of the GE seeds (Bennett et al. 2006; Morse et al. 2007; Glover 2010; Arora and Bansal 2012; Gutierrez 2018). During the early period of diffusion, the seed costs of Bt seeds exceeded those of conventional seeds up to four times (Stone 2011; Arora and Bansal 2012). However, from 2006 onwards when the government intervened in seed pricing by limiting the maximum price per seed packet and the market competition for Bt technology increased, the cost difference declined and the discussion abated (ibid.). Currently, the debate of increased input costs has shifted to re-increasing pesticide costs associated with secondary and reoccurring target pests (PBW) (Gutierrez et al. 2015; Flachs 2017; Gutierrez 2018; Kranthi and Stone 2020). As Gaurav and Mishra conclude, there has been an “increase in riskiness” of cotton production since the introduction of Bt cotton technology (2012, p. 23f.).

Louis (2015) adds insightful qualitative findings to the debate by underlining the restricted choice farmers have despite the associated agricultural risk. Whereas initially, mainly large farmers cultivated Bt cotton, the crop has now been adopted on a large scale, even by small or marginal farmers (Gaurav and Mishra 2012; Gutierrez et al. 2015; Louis 2015). In this regard, Louis (2015) outlines a paradox that cotton farmers face, in which especially resource-poor farmers are constrained in their cultivation choice and simply cannot afford subsistence farming or a diversified agriculture, but are pushed towards high-risk cotton monocropping systems for short-term economic benefits (Louis 2015). Despite of being aware of the economic risks associated with the crop, they grow only cotton in order to maximize their short-term cash-earning opportunities (Louis 2015). This is consistent with Gutierrez (2018, p. 2206), who describes Bt cotton as a "stranglehold on subsistence farmers".

2.5.6 Farmer suicides

Throughout India’s recent agricultural past, alarming waves of farmer suicides were reported in the country (Vasavi 2009; Stone 2011; Gupta 2017). Over the past two decades, the country counted around 300,000 suicides committed by farmers (Thomas and de Tavernier 2017). The influence of Bt cotton technology on these waves of farmer suicide, however, remains contested (Herring 2005; Thomas and De Tavernier 2017).

While some clearly link the dramatic problem to Bt cotton introduction, even terming the seeds as “suicide seeds” (Shiva et al. 2000), others point out the temporal incongruities of such connections (Stone 2011; Kranthi and Stone 2020). As Stone (2011) argues, the GE seeds had by some even been attributed as the cause for farmer suicides before they were used in India. One example for this temporal incongruity is the suicide wave in Warangal district (Telangana) that took place from 1998-2000 (Stone 2011; Kranthi and Stone 2020). Even after the authorization of Bt seeds in 2002, suicide rates have not increased with rising diffusion rates of the GE seeds (Kranthi and Stone 2020).

Gutierrez et al. (2015) hence offer a more differentiated perspective on the issue by outlining the significance of (the lack of) access to irrigation for Bt cotton growers. As they describe, suicide rates among farmers are higher in southern Indian cotton-producing states, where rainfed cultivation systems are prevalent (Gutierrez et al. 2015; Gutierrez 2018). Congruously, they argue Bt cotton to be an acceptable option for irrigated cotton areas, whereas in areas characterized by low yields with high variability, the risk of bankruptcy, and in turn suicide, increases (Gutierrez et al. 2015). Gutierrez (2018) hence points out that in the case of failure to produce profitable yields, farmers pile up debts that result in elevated suicide rates. The influence of economic factors has also been picked up by Thomas and De Tavernier (2017, p. 17), who found “a definite association between economic factors associated with Bt cotton-farming and farmer-suicide”, and according to Gutierrez et al. (2015), annual suicide rates in rainfed areas are inversely related to farm size and yield. While they further report a direct relation of annual suicide rates to rising Bt cotton adoption, they argue the causal link to lie in the increased economic risk faced by farmers, particularly in rainfed areas (cf. Louis 2015). Therefore, they sum up that “economic distress can be a proximal cause of suicide”, rather than Bt cotton as such (Gutierrez et al. 2015, p. 11).

2.6 The contribution of this research

This study is embedded in the prevailing, above-outlined controversy that surrounds GE crops in general and Bt cotton technology in India in specific (Glover 2010; Kathage and Qaim 2012; Kranthi and Stone 2020; Luna 2020). In order to contribute to this scientific debate, I present four peer-reviewed papers that have been published (chapters 5 (Najork et al. 2021), 6 (Najork et al. 2022), and 8 (Friedrich et al. 2022), or have been accepted for publication (chapter 7 (Najork and Keck (*forthcoming*)) in four different international scientific journals. I contributed to three of these publications as sole first author (chapters 5, 6, and 7), while I contributed to the fourth paper (chapter 8) in the form of a shared first authorship. For all four publications, the process of peer-reviewing is completed.

In the first part of this thesis, I focus on how the implementation of the technology has affected Bt cotton-cultivating households in the Karimnagar district of Telangana on an individual level. The publication by Najork et al. (2021) *‘The Return of Pink Bollworm in India’s Bt Cotton Fields: Livelihood Vulnerabilities of Farming Households in Karimnagar District’*[13] (presented in chapter 5) not only offers an up-to-date, in-depth analysis of the socio-economic implications of the technology on farming households’ livelihoods in general, but also provides first insights on the socio-economic effects of the newly emergent pest outbreaks on Bt cotton-farming households in Telangana. As such, the publication contributes to the broad current scientific debate on the implications of Bt cotton technology in countries of the Global South in general (Qaim 2003; Stone 2007; Kathage and Qaim 2012; Kranthi 2015, 2016; Stone and Flachs 2017; Flachs 2019a), and non-irrigated cotton-cultivating areas in particular (Ramasundaram et al. 2007; Glover 2010; Gaurav and Mishra 2012; Gutierrez et al. 2015; Kumar 2015; Gutierrez 2018; Matthan 2021). The case study’s findings add to the evidence that confirms

[13] Najork, K., Gadela, S., Nadiminti, P., Gosikonda, S., Reddy, R., Haribabu, E., and Keck, M. 2021. The return of pink bollworm in India’s Bt cotton fields: livelihood vulnerabilities of farming households in karimnagar district. *Progress in Development Studies* 21(1): 68–85. doi:10.1177/ 14649934211003457.

the return of the PBW to large parts of cotton cultivation areas in Telangana (cf. Naik et al. 2018; Fand et al. 2019; Tabashnik and Carrière 2019). While farmers still reported Bt-related benefits for the early years of technology implementation, unexpected collapses in yields are now reported with negative effects on farming households in regard to debt increases (cf. Vasavi 2012, 2020). These new insights shed light on farmer livelihoods and altered vulnerabilities (cf. Ramamurthy 2000; Scoones 2008), as they show how the vulnerability context of Bt cotton farmers has changed with the introduction of Bt cotton. By outlining how the random malfunctioning of the technology and the entailed pest outbreaks have increased oscillations in farmers' cotton-related effective income generation, the publication also contributes to risk and vulnerability research in this field (cf. Gaurav and Mishra 2012; Gutierrez et al. 2015; Louis 2015; Gutierrez 2018). For reasons of transparency, table 2 provides a detailed overview of the individual contributions of the authors to the manuscript.

Table 2: Individual contributions of the authors to the publication 'The Return of Pink Bollworm in India's Bt Cotton Fields: Livelihood Vulnerabilities of Farming Households in Karimnagar District'

Author contributions	Author
Conceptualization	K.N., M.K.
Methodology	K.N., M.K.
Research	K.N., M.K.
Data acquisition	K.N., M.K., research partners, assistants
Data preparation	K.N., M.K., assistants
Data analysis	K.N., M.K.
Original draft preparation	K.N., M.K.
Review and text editing	K.N., M.K.
Visualization	K.N., M.K.
Supervision	M.K.
Project administration	M.K.
Funding acquisition	M.K.

Based on the findings of the first case study, the second part of this thesis analyzes the above-described effects from a political economic perspective. The publication by Najork et al. (2022) *'Bt Cotton, Pink Bollworm, and the Political Economy of Sociobiological Obsolescence: Insights from Telangana, India'*[14] (presented in chapter 6) considers structural implications of the changed vulnerability context of Bt cotton-cultivating households in Telangana by implementing the political economic approach of 'accumulation by dispossession' (ABD) (Harvey 2005). On a broader scale, above-mentioned oscillations in Bt cotton yields were found to be balanced only by economically better-off farming households, whereas resource-poorer farmers were found to be pushed into a cycle of dispossession, while successively

[14] Najork, K., Friedrich, J., and Keck, M. 2022. Bt cotton, pink bollworm, and the political economy of sociobiological obsolescence: insights from Telangana, India. *Agriculture and Human Values*: 1-20. doi:10.1007/s10460-022-10301-w.

releasing capital and thus providing opportunities of appropriation for other actors. With that, the research contributes to current considerations of ongoing processes of ABD, particularly in countries of the Global South (Castree 2007; Cáceres 2015; Carroll 2017). Conceptually, the publication thus adds to David Harvey's (2005, 2007) notion of ABD by integrating the role of technologies as mechanisms of neoliberalization processes (cf. Luxemburg 2003; Peck and Theodore 2007; Brenner et al. 2010; Haribabu 2014). By exposing resultingly reproduced prevalent hegemonic structures in the neoliberal Indian Bt cotton nexus, this research further adds to Gramscian considerations of hegemony in the proclaimed Indian agrarian crisis (cf. Jakobsen 2018a, 2018b; Brown 2019). For reasons of transparency, table 3 provides a detailed overview of the individual contributions of the authors to the manuscript.

Table 3: Individual contributions of the authors to the publication 'Bt Cotton, Pink Bollworm, and the Political Economy of Sociobiological Obsolescence: Insights from Telangana, India'

Author contributions	**Author**
Conceptualization	K.N., J.F., M.K.
Methodology	K.N., J.F., M.K.
Research	K.N., M.K.
Data acquisition	K.N., J.F., M.K., assistants
Data preparation	K.N., J.F., assistant
Data analysis	K.N., J.F.
Original draft preparation	K.N., J.F., M.K.
Review and text editing	K.N., J.F., M.K.
Visualization	K.N., J.F., M.K.
Supervision	M.K.
Project administration	M.K.
Funding acquisition	M.K.

The third part of the thesis further extends the study's focus by addressing the role of state authorities on an administrative level. The manuscript by Najork and Keck (*forthcoming, accepted for publication in April 2022*) *'Mistranslating refuge crops: analyzing policy mobilities in the context of Indian Bt cotton production'*[15] (presented in chapter 7) sheds light on the policy assemblage of the Indian Bt cotton sector. As it outlines policy mobilities and mistranslations that went along with the adaption of Bt refuge policies, the study helps to deconstruct the prevalent narrative that blames farmers for the failure of Indian resistance management strategies (cf. ISAAA 2017; Mohan 2017, 2018). By means of an in-depth analysis of documents related to Indian Bt cotton refuge policies (cf. chapter 2.2.2), the article unravels the administrative side of the policy assemblage and debunks serious mistranslations that have occurred on the side of state authorities (cf. Tabashnik and Carrière 2019; Tabashnik et al. 2021). These considerations are linked to a cluster analysis of the Telangana cotton-

[15] Najork, K. and Keck, M. (*forthcoming*). Mistranslating refuge crops: analyzing policy mobilities in the context of Indian Bt cotton production. *Geographica Helvetica*, accepted for publication.

cultivating peasantry, showing that especially resource-poorer farmers are pushed toward short-term profit maximization, and hence refrain from implementing refuge policies as these are associated with economic sacrifices (cf. Louis 2015; Stone and Flachs 2017). With that, the publication helps to understand that moral economic questions must be considered for a successful implementation of refuge crop policies and that policy-making authorities should be held accountable, not only subaltern actors like Bt cotton farmers. For reasons of transparency, table 4 provides a detailed overview of the individual contributions of the authors to the manuscript.

Table 4: Individual contributions of the authors to the manuscript 'Mistranslating refuge crops: analyzing policy mobilities in the context of Indian Bt cotton production'

Author contributions	Author
Conceptualization	K.N., M.K.
Methodology	K.N., M.K.
Research	K.N., M.K.
Data acquisition	K.N., M.K., assistants
Data preparation	K.N., assistant
Data analysis	K.N.
Original draft preparation	K.N., M.K.
Review and text editing	K.N., M.K.
Visualization	K.N., M.K.
Supervision	M.K.
Project administration	M.K.
Funding acquisition	M.K.

The fourth part of the thesis, published under shared first authorship, finally addresses more abstract, discursive implications of Bt cotton technology implementation and innovation in the neoliberal Indian Bt cotton nexus. The publication by Friedrich et al. (2022) *'Bioeconomic fiction between narrative dynamics and a fixed imaginary: Evidence from India and Germany'*[16] (presented in chapter 8) contributes to considerations of economic sociology related to imagined futures of bioeconomic actors in the field of biotechnological innovation (cf. Beckert 2013b, 2018; Beckert and Bronk 2019). As such, it expands our knowledge on the imaginaries that shape bioeconomic innovation and the co-constituted narratives employed by actors to present technological innovations. By means of a comparative case study including bioeconomic innovation actors from India and Germany, the study provides insights into research on bioeconomic visions (cf. Bugge et al. 2016; Hausknost et al. 2017) in addition to making contributions to research in the field of economic sociology. For reasons of

[16] Friedrich, J., Najork, K., Keck, M., and Zscheischler, J. 2022. Bioeconomic fiction between narrative dynamics and a fixed imaginary: Evidence from India and Germany. *Sustainable Production and Consumption* (30): 584-595. doi:10.1016/j.spc.2021.12.026, *published in the form of a shared first authorship.*

transparency, table 5 provides a detailed overview of the individual contributions of the authors to the manuscript.

Table 5: Individual contributions of the authors to the publication ‘Bioeconomic fiction between narrative dynamics and a fixed imaginary: Evidence from India and Germany’

Author contributions	**Author**
Conceptualization	J.F., K.N.
Methodology	J.F., K.N.
Research	J.F., K.N.
Data acquisition	J.F., M.K.
Data preparation	J.F., K.N., assistants
Data analysis	J.F., K.N.
Original draft preparation	J.F., K.N., M.K., J.Z.
Review and text editing	J.F., K.N., M.K., J.Z.
Visualization	J.F., K.N., M.K., J.Z.
Supervision	M.K., J.Z.
Project administration	M.K., J.Z.
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3 Conceptual framework

This thesis aims to contribute to the scientific controversy surrounding agricultural biotechnology implementation in India by empirically addressing questions on the rural socioeconomy and vulnerability-related implications arising from the adoption of Bt cotton technology in general, as well as the recent developments of target pest re-occurrences in specific, for Indian cotton-farming smallholders. Using the case of Bt cotton adoption in Telangana in India, this research aspires to reveal hitherto neglected perspectives of marginalized actors that have so far been unaddressed in the scientific debate and have thus remained excluded from political decision-making processes. In order to achieve the depiction of hitherto excluded perspectives of subaltern actors, and to outline the complex global-local interconnections of the implementation of agricultural biotechnology, this research approaches the scientific controversy on agricultural biotechnology from a pluralized conceptualization of geographical perspectives, including considerations from the fields of development geography, political economy, and economic sociology.

This chapter provides an overview of the applied conceptual approaches, which I, in accordance with the broadening thematic focus, expand throughout my research (cf. fig. 1)[17]. For the in-depth analyses that constitute the four main parts of this thesis, I hence revert to different conceptual approaches that I link with the broader notion of agri-food geographies. For part 1, to investigate the socio-economic implications of the technology implementation on the livelihoods of Bt cotton-farming households and their responses to the re-occurrence of the target insect, I draw on classical action-oriented development geographical concepts of sustainable livelihoods and vulnerability studies (chapter 5). For part 2, examining the political economic implications of the farmers' altered vulnerability context, I embed conceptual notions of ABD and Gramscian hegemonic reflections into observations of technology as a form of variegated neoliberalism (chapter 6). In part 3, I explore the Bt cotton-related policy assemblage and involved refuge crop policy mobilities by applying recent considerations from policy assemblages, mobilities, and mutations affiliated with STS to moral economic considerations (chapter 7). In part 4, I retrace the narratives and imaginaries related to biotechnology innovation by relying on thinking that engages with economic sociology and the notions of imagined futures and fictional expectations (chapter 8).

[17] Parts of this chapter have been adapted from the papers and the manuscript that constitute this thesis (cf. chapters 5-8; Najork et al. 2021; Najork et al. 2022; Friedrich et al. 2022; Najork and Keck (*forthcoming*), as well as from the abovementioned master's thesis (Najork, K. 2019. The Impact of Bt Cotton on Peasant Livelihoods in Karimnagar District in Telangana, India).

3.1 Vulnerability

Derived from the Latin *vulnerare* (to wound), the term *vulnerability* refers to the susceptibility to be wounded or harmed (Füssel 2007; Ford et al. 2018). While originating from research of the natural hazards field in the 1970s and 1980s (Timmerman 1981; Liverman 1990), as well as entitlement-based explanations of vulnerability (Sen 1981; Adger 2006), vulnerability studies were then prominently employed by climate change research in order to assess the effects of changes in the climate on human systems (Füssel and Klein 2006; Ford et al. 2018; Intergovernmental Panel on Climate Change (IPCC) 2022). From this historical review follows that vulnerability research is usually employed in multidisciplinary fields of study at the verge of human–environment relationships (Adger 2006; Paul 2013). (Human) geography as well as human ecology thus have a "disciplinary legitimacy" to employ vulnerability approaches and both particularly contributed to the field (Paul 2013, p. 63; see also Bohle 2001; Adger 2006; Füssel 2007).

Today, the term has widely spread across various research fields and disciplines, and is used as a central concept in research of ecology, sustainability science, poverty and development, land and climate change, or secure livelihoods (Füssel 2007; Ford et al. 2018). This multidisciplinary use caused the term to fray in regard to its conceptual uniformity, as it is now "defined, interpreted and applied in various ways" due to the different ontologies and methods of the various fields engaged in vulnerability research (Hufschmidt 2011, p. 621). Therefore, no general definition covering all disciplines involved in vulnerability studies currently exists (Adger 2006; Costa and Kropp 2013; Paul 2013). Overall, however, the term addresses the degree of harm or damage a system (e.g., an individual person, an entire community, a city, or a region) experiences due to the incurrence of and exposure to risk (e.g., in the form of natural hazards) and its degree of ability to cope (Watts and Bohle 1993; Füssel 2007; Hufschmidt 2011; Ford et al. 2018). As such, the concept covers external factors, i.e., a system's exposure to shocks and stressors (Chambers and Conway 1992; Bohle 2001; Füssel and Klein 2006), as well as internal factors, i.e., the system's capacity to cope with and recover from stresses (Birkmann 2006; Costa and Kropp 2013). Consequently, the varying subject areas share common and overarching components linked to the concept of vulnerability: resilience, marginality, susceptibility/sensitivity, adaptability/adaptation, fragility, risk, exposure, sensitivity, coping capacity (Liverman 1990; Adger 2006; Füssel and Klein 2006; Costa and Kropp 2013; Keck and Etzold 2013).

The key notions *exposure, susceptibility, coping,* and *adaptation* were particularly relevant for my research and will be defined in more detail. *Exposure* is concerned with the degree and nature of external stressors or shocks, such as environmental impacts, and is characterized by the parameters of the frequency, magnitude, and duration of such stressors or shocks

(Adger 2006). *Susceptibility*, on the contrary, describes the internal factors that determine the extent to which external factors can cause harm on a system (Weichselgartner 2016). *Coping* refers to a system's ability of immediate reaction to overcome stresses (Keck and Sakdapolrak 2013). Finally, *adaptation* covers the capability to learn from past shocks and stresses and to expand options of coping in the long-term (Keck and Sakdapolrak 2013). As I thematized the vulnerability of Bt cotton-farming households in this study, the 'system' addressed here refers to Bt cotton farmers' household livelihoods.

3.2 Sustainable Livelihoods

The *Sustainable Livelihood Approach* (SLA) is an outgrowth of the vulnerability concept and emerged from its branch of entitlements research (Sen 1981; Adger 2006; De Haan 2012). Targeting to explain the causes of famine, entitlements theory focalizes the effective demands for food and the means of receiving it, instead of focusing on shortfalls in the production of food (Sen 1981; Adger 2006). In this way considering livelihood systems as a whole from an actor-oriented perspective, the SLA aims at considering the entire vulnerability context of the respective social unit under investigation (e.g., a household) and allows for a realistic understanding of people's livelihoods (Chambers and Conway 1992; Conway et al. 2002; Carney 2003).

Against this backdrop, in the late 1990s, livelihood studies were brought to the center stage of development studies (Chambers and Conway 1992; Conway et al. 2002; Carney 2003; De Haan 2012). The concept was therefore strongly supported by the British Department for International Development (DFID) and adopted by other development agencies (e.g., Oxfam, United Nations Development Programme (UNDP)) (Moser 2008; De Haan 2012). In their foundation paper of sustainable livelihood research, Chambers and Conway (1992, p. 6) offer the prominent definition of livelihoods:

> *"[A] livelihood comprises the capabilities, assets (stores, resources, claims, and access) and activities required for a means of living: a livelihood is sustainable which can cope with and recover from stress and shocks, maintain or enhance its capabilities and assets, and provide sustainable livelihood opportunities for the next generation; and which contributes to net benefits to other livelihoods at the local and global levels and in the short and long term."*

Key elements of the livelihood approach alluded to in Chambers and Conway's (1992) pioneering definition, including central elements, strategies, as well as outcomes of livelihood systems, are addressed in the *Sustainable Livelihood Framework* (SLF), which is depicted in figure 6.

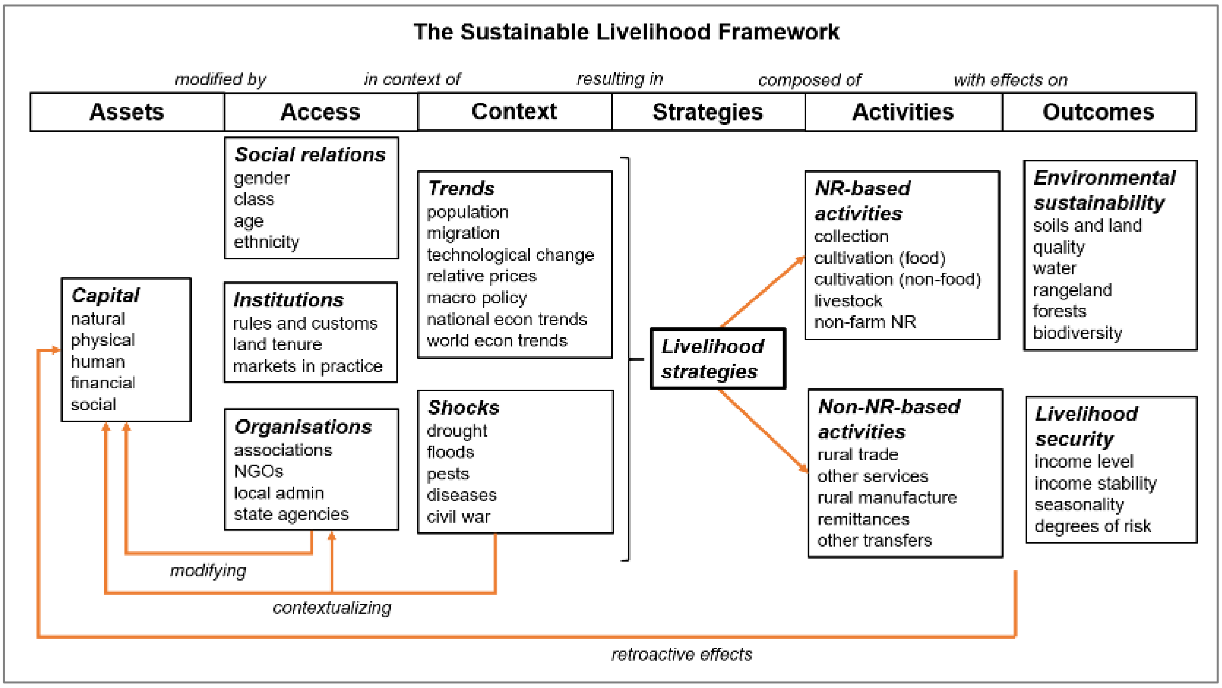

Figure 6: The Sustainable Livelihood Framework (own sketch, redrawn and adapted from Ellis 2000a and DFID 1999)

Although the framework's structure varies in practice, as the parameters are interdependent and interrelated, it provides a plausible and intuitive structure to discuss the elements of livelihoods in theory (cf. fig. 6). For the research presented here, the examined livelihood units were Bt cotton-cultivating households.

The framework first depicts the livelihood *assets*, which are composed of five different kinds of capitals (natural, physical, human, financial, and social) (Scoones 1998; Ellis 2000a, 2000b; Morse and McNamara 2013). Natural capital refers to a livelihood's resources, like public goods (atmosphere, or biodiversity), but also resources directly involved in the process of production (land, water, and biological resources) (DFID 1999; Ellis 2000a; Moser 2008; Morse and McNamara 2013). Physical capital implies the infrastructure which is available to a livelihood (e.g., roads, canals, markets) (ibid.). Human capital refers to the available labor, but also to a livelihood's education, skills, knowledge, and health (ibid.). Financial capital refers to stocks of money, such as savings, or credits and loans (ibid.). Savings are generally the preferred form of stocks because they do not involve commitments or obligations (DFID 1999). Social capital refers to community and social claims, e.g., belonging to a certain social group (DFID 1999; Ellis 2000a; Moser 2008; Morse and McNamara 2013). These assets are modified by the *access* that a livelihood unit has regarding its social relations (gender, class, age, and ethnicity), its surrounding institutions (rules and customs, land tenure, and markets in practice) as well as organizations (associations, NGOs, local admin, and state agencies) (Scoones 1998; Ellis 2000a). The two variables of assets and access always need to be considered in their particular *context*. This context is comprised by trends (population, migration, technological change, relative prices, macro policy, and national as well as world economic trends) and shocks (drought, floods, pests, diseases, and civil war), which both shape a livelihood's assets and access thereto. These aspects result in different *livelihood strategies,* which are again composed of varying *activities* that a livelihood unit adapts in order to generate its means of survival (Ellis 2000a). These can either be based on natural resources (collection, cultivation of food or non-food, livestock, or non-farm natural resources) or be non-natural-resource-based (rural trade, other services, rural manufacture, remittances, or other transfers). Scoones (1998) further differentiates between strategies of agricultural intensification or extensification, livelihood diversification, and migration. Finally, all these key parameters affect a livelihood's *outcomes* and can lead to livelihood security (including the income level and its stability, seasonality, and degrees of risk) as well as environmental sustainability (quality of soils and land, water, rangeland, forests, and biodiversity) (Ellis 2000a). The first is regarded as the social, the second as the environmental dimension of sustainability (Chambers and Conway 1992). A livelihood system is regarded as sustainable if it is able to "buffer or cope with stresses and shocks and can recover from them without depleting its available material and immaterial basis of resources" (Krüger 2003, p. 11, own translation; see also Carney 1998). Livelihood security and environmental sustainability therefore represent the opposite of vulnerability (Ellis 2000b).

3.3 Political economic embedding

As argued by Watts and Bohle (1993) in their landmark article '*Hunger, famine and the space of vulnerability'*, vulnerability research should not be limited to an individual level of focus but should go beyond and take the structural properties of the embedding political economy into account. These structural realities decisively influence livelihood conditions "on the ground" and affect households' capacities to cushion resulting negative effects, particularly in times of crisis. This research hence aims to understand the political economy behind the altered vulnerability context of Bt cotton farmers in Telangana by considering the linkages of individual household vulnerabilities and their structural political economic contexts.

The concept of political economy, which originates from eighteenth-century English mathematicians and economists such as Adam Smith and Thomas Malthus, has since expanded as it has continuously absorbed different currents of thought related to the fields of politics, economics, and sociology (Weingast and Wittman 2011). While originally referring to the science of managing economics on a national scale, and hence setting a particular focus upon political and economic subject matters, it has developed into an umbrella term with partly contradictory meanings, as it is understood as an area of study as well as a methodological approach investigating both economic (analysis of individual rationality) and sociological (analysis on an institutional level) issues (Weingast and Wittman 2011). As a result, political economy as a concept is now understood as a broad synthesis of these various strands (Weingast and Wittman 2011).

As has been done by other geographic scholars (Harvey 2003, 2005; Glassman 2006; Castree 2007; Carroll 2017), throughout this thesis, I too adhere to the Marxist understanding of this mosaic of perspectives, which focuses attention on the question of “how the ownership of the means of production influenced historical processes” (Weingast and Wittman 2011). It has been established in the literature that this view on political economy includes the consideration of power asymmetries and constantly reinforcing inequalities, e.g., in access to resources, and therefore politicizes vulnerability “in the sense that it traces its roots to explicitly political processes” (Mikulewicz 2018, p. 24; cf. Watts and Bohle 1993; Tanner and Allouche 2011). Resultingly, as Eriksen et al. (2015, p. 527) put it, the “idea that power and politics shape how environmental change and societies co-emerge is certainly not new”. It has thus already been highlighted that “intersecting processes of social relations, divisions of labor, political economies, and environmental conditions” are involved in shaping vulnerabilities (Blaikie et al. 1994; Eriksen et al. 2015). While issues like poverty, or low levels of education certainly do not lose in importance, shifting the focus to power- and politics-related questions provides a more nuanced and holistic understanding of the vulnerability context of local people, and thus helps to comprehend why some remain vulnerable while others manage to adapt (Mikulewicz 2018). As Mikulewicz (2018, p. 24) outlines, “local vulnerability and adaptation, rather than just social, are explicitly political by nature” (cf. Eriksen et al. 2015; Nightingale 2015; Taylor 2014).

The query of Watts and Bohle (1993) to go beyond an individual level of investigation and to consider broader implications of the underlying political economic structures has thus already been followed by other scholars since the release of their pioneering article. Especially studies emerging from the origin research fields of vulnerability studies, i.e., natural hazards research (Yasir 2009; Swamy 2018) and the later following vulnerability research concerned with climate change (Barnett and Adger 2007; Adger and Brown 2009; Tanner and Allouche 2011; Ribot 2014; Taylor 2014; Eriksen et al. 2015; Nightingale 2015; Mikulewicz 2018; Barnett 2020), have paid heed to the request of the two authors and have included political economic considerations into their vulnerability analyses. Moreover, studies focusing on urban livelihoods (Pelling 2002; Nzeadibe and Mbah 2015; Patel et al. 2020), particularly urban livelihoods located in the Global South, have addressed these linkages as well. However, research examining rural livelihoods has, with few exceptions (Ellis 2006; Chomba et al. 2015), missed to specifically include the broader structural implications of political economic embeddings. As Ellis (2006, p. 393) still outlines in his article more than ten years after Watts and Bohle had published theirs in 1993, “vulnerability is not a term typically associated with political economy discourses”.

Next to its thematic contributions in the Bt cotton controversy, this study intends to shed light on these little-studied unknowns of rural livelihoods by adding to current research in this intersection of the political economy realm and vulnerability studies. The implementation of a Marxist approach on political economic thinking in this area of focus intends to expose hitherto neglected, subaltern, and marginalized perspectives. Congruously, the concepts used here, i.e., ABD and moral economic observations, have emerged from this line of thought. By looking at the current neoliberal Indian regime of GE agriculture, this thesis adds yet another novel variable to the analysis, which is that of technology-induced vulnerability. Addressing the neoliberal character of the superordinate agricultural regime, I regard Bt cotton technology as a neoliberal technology that constitutes the context in which to analyze farmer vulnerability.

3.3.1 The context of a variegated neoliberalism

Neoliberalism generally involves the politically initiated restructuring of institutional frameworks for intensified marketization and commodification (Harvey 2007; Brenner et al. 2010). Until the early 2000s, neoliberalism was mostly viewed as a totalizing hegemonic structure characterized by a fixed set of attributes with predetermined outcomes that spread across national borders (Ong 2007). This ‘master concept’ was commonly understood as a “bundle of (favoured) policies, as a tendential process of institutional transformation, as an emergent form of subjectivity, as a reflection of realigned hegemonic interests, or as some combination of the latter” (Brenner et al. 2010, p. 183). In contrast, the contemporary understanding of neoliberalism is more like that of a variegated nexus of constitutively uneven but cumulatively transformative processes and mechanisms (Peck and Theodore 2007; Brenner et al. 2010).

Brenner et al. (2010, p. 184) argue that neoliberalization processes first emerged in the 1970s, in an already unevenly developed institutional landscape. While altogether contributing to facilitating marketization and commodification, neoliberal mechanisms in turn intensify “the uneven development of regulatory forms across places, territories and scales” (ibid.; cf. Theodore and Peck 2007). In accordance with this course described as multifaceted, Harvey (2005, p. 1) speaks of “several epicentres” in regard to the emergence of neoliberalism. Brenner et al. (2010, p. 198) therefore argue that there is no “single worldwide neoliberal regime” but rather hypothesize that successive waves of neoliberal transformation occur at all spatial scales culminating in “distinct yet interdependent pathways of neoliberalization”. Accordingly, neoliberalism can be understood as a logic of governing that migrates and is selectively taken up in various political contexts (Ong 2007).

Due to my focus on agricultural biotechnology in the form of Bt cotton in this research, I focus on the role of technology as one mechanism of ongoing processes of neoliberalization. I therefore outline the weight of technology as one possible building brick in the above-sketched neoliberal variegation.

3.3.2 Biotechnology as a facet of a variegated neoliberalism

Harvey (2003) outlines that neoliberal societies tend to follow a 'technological fetish' by endowing technologies with powers that they in fact do not have. As such, they are ascribed the "ability to solve social problems, to keep the economy vibrant, or to provide us with a superior life" (ibid., p. 3). This fetish leads to the belief that technological progress is both inevitable and good in itself, and finally, that there is a technological solution to whatever problems a subject or society is encountering – a 'technological fix' (2003, p. 3, ibid. 2007). However, as Harvey (2003, 2007) shows, technological fixes in general do not truly serve to actually solve the aforementioned economic or societal problems but rather enable further accumulation of capital. In economic contexts, this can generate trends of technological change to a destabilizing, or even counterproductive degree (Harvey 2007, p. 69). As this fetish belief in technology is also relied upon in the entrepreneurial common sense, which is firmly anchored in neoliberal theory, the coercive powers of competition are attributed the potency to create a market drive in the search of ever new products, production methods, and organizational forms (Harvey 2007, p. 68). In this context, corporate strategies emerge to create new markets that are primarily dedicated to producing new demands for products that hitherto have not existed and had no market (Harvey 2007, p. 69). To keep the machinery of creating demands alive, predetermined breaking points are integrated into products such as consumer electronics, clothing, and automobiles, causing obsolescence and thus ensuring long-term sales of ever-new products through a shortened product life cycle (e.g., white goods industry) (Haribabu 2014). The use of inferior materials, for example, can initiate breaking points that force consumers to repeatedly buy new products (Haribabu 2014). While this obsolescence is planned and technological in essence, Haribabu (2014) argues that the seed industry also employs such strategies, as he outlines for Bt cotton. In the research presented here, I therefore regard Bt cotton technology as a neoliberal technology that provides the context for analyzing farmer vulnerability.

3.3.3 Accumulation by dispossession

In order to analyze the entanglements of (bio)technology as a form of a variegated neoliberalism with farmers' changed vulnerability context, I rely on geographical considerations of political economy by building upon the notion of 'accumulation by dispossession' (ABD). I argue that Bt technology in its current form is one of the main drivers of processes that Harvey (2005) describes as ABD. To theorize his concept, he draws upon Marxist understandings of political economy as he reverts to Karl Marx's (1967, p. 714) notion of 'primitive accumulation'. Against this backdrop, Harvey (2005) focuses on the new strategies developed in capitalist countries under neoliberal governments aiming to transfer public wealth into an increasingly concentrated private sector. Marx used the concept of primitive accumulation to grasp the precondition of capitalism marked by late sixteenth-century English enclosures, in which elites appropriated peasant land to graze sheep and engage in the highly profitable wool trade while peasant farmers became landless and thus obliged to engage in wage labor (Perelman 2000; Di Muzio 2007). With his reading, he especially turned against the bourgeois mythologies framing capital as generated through the frugality of the elite, by replacing it with a history of violent expropriation, colonial expansion and racialized enslaved labor (Di Muzio 2007; Burnard 2019). However, for Marx, the "historical process of divorcing the producer from the means of production" was confined to a particular (if indefinite) period before the capitalist accumulation regime fully locked in. Following Luxemburg (2003) and Harvey (2005), in contrast, the violent expropriation of means of production represents a process that is still taking place in capitalist economies to date (Glassman 2006; Castree 2007; Carroll 2017; Rosa et al. 2017). The removal of agricultural producers from the countryside, especially in peripheral regions, and the consolidation of more privatized control over resources remain very important processes today, affecting billions of people especially in the Global South (cf. Luxemburg 2003). As Harvey shows, primitive accumulation – or its present form of ABD – has turned out to be an inherent and continuous element of current capitalist societies, and its range of action extends to the entire world (cf. Luxemburg 2003; Glassman 2006; Carroll 2017).

According to Harvey (2019), the neoliberal turn has hitherto neglected the still ongoing problems of capital accumulation. He argues that neoliberalism has failed to stimulate worldwide growth, as it has merely achieved a redistribution of capital instead of its generation. In consequence, he reasons that ways had to be found to shift wealth either within a population towards the upper class or from vulnerable to richer countries (Harvey 2019, p. 43). In this regard, Harvey follows Luxemburg in arguing that capitalism always needs an "other" outside of itself for stabilization (Harvey 2013, p. 140). Processes achieving such redistribution are termed by him as mechanisms of ABD (ibid). These include, for example, the privatization and commodification of land or water, implying the expulsion of peasants, the commodification of labor power, and the conversion of collective into private property rights (Harvey 2013, 2019). From this results that the right of ownership changes into appropriation of other people's property in the course of accumulation (Harvey 2013).

A necessary condition to initiate ABD is the existence of overaccumulation. As a prerequisite for mechanisms of ABD to be operated, dormant capital surplus has to lie fallow without profitable outlets for this capital being available (Harvey 2013, p. 149). If then, assets are released through ABD at very low cost, for example through crises that enforce the devaluation of such assets, these can later be seized via capital and turned to profitable use (Harvey 2005, p. 149ff; Hall 2013). Thus, recurring crises constitute both an essential feature of capitalism itself and a major instrument for ABD. The state, with its hegemonic license to define what is legal and what is not, is not only an accomplice in this process. Rather, the state plays an active role in coordinating new forms of dispossession, in providing normative frameworks that legally support it, and in legitimizing the process of creating dispossessed social actors in the name of growth and progress (Cáceres 2015, p. 117; Harvey 2019). As Harvey argues, unless the state steps in to counteract, the concentration of wealth, the restoration of class power, and with that the asymmetric power relations rather tend to increase than dwindle over time (2005, p. 68).

In the realm of geographical research involved with the notion of ABD, the concept has lately been mostly applied to questions of land grabbing (Levien 2012; Hall 2013; Gellert 2015; Zambakari 2018). This is most likely due to the close link to the core of the geographical discipline, which, in its origin form, focuses narrowly on questions involving spatial matters, and due to the clear parallels that issues of land grab seem to show with original processes of dispossession of peasants from their land in historical ‘primitive accumulation’ processes. While recent studies have started applying the concept to technology-related questions involved with the agrarian capital expansion in countries in the Global South (Cáceres 2015; Cáceres and Gras 2020; Gras and Cáceres 2020) and specifically to the diffusion of GMOs (Carroll 2017), these have focused on the role of technology in appropriating nature. This research adds to such recent contributions in examining the role of (bio)technology as a form of a variegated neoliberalism in processes of ABD, but differs from this prior research in that it explicitly links processes of accumulation and dispossession to the altered vulnerability context of Bt technology applying farmers.

3.3.4 Moral economics of rural Indian Bt technology implementation

In order to highlight the local level of analysis, this chapter now turns to the notion of moral economy, as this concept grasps micro-economic practices in situ in the form of local thought patterns, institutions, and networks of reciprocity and obligation while linking them to power relations on a larger scale (Sayer 2000; Palomera and Vetta 2016). In this way moral economy assesses the justification and fairness of economic relations and practices at local spaces, and analyzes and evaluates economic matters from a “moral point of view” (Sayer 2017, p. 4; see also Palomera and Vetta 2016; Carrier 2018). While the concept of moral economy dates back to the 18th century, the term was introduced by the historian E. P. Thompson with his 1971 article *‘The moral economy of the English crowd in the eighteenth century’*. With this essay, Thompson addresses the agency of “the crowd” by thematizing food riots of the urban working population in 18th-century England (Edelman 2005, 2012; Götz 2015; Palomera and Vetta 2016; Carrier 2018). Later, James Scott related the concept to more rural contexts by linking it to peasant studies with his 1976 article '*The moral economy of the peasant'*, in which he discusses examples of peasant collective action in early-20th-century South East Asian peasant rebellions (ibid.). In doing so, he relates the micro setting of peasants' everyday life to superordinate transformations and exposes entanglements between them, e.g., between farmers' livelihoods and developments like the emergence of colonial states or the free-market expansion (Palomera and Vetta 2016). In this context, he particularly addresses the matter of peasant subsistence by arguing that peasants are "risk-averse social agents" with a "safety-first principle" as their guiding value, and thus contrasts them with the neoclassical economics' homo oeconomicus or "the would-be Schumpeterian entrepreneur" (Scott 1976, p. 4, quoted from Palomera and Vetta 2016, p. 417).

In this thesis, moral economic considerations therefore complement those of political economy, as they serve to re-embed the broader political economic context to economic action "on the ground". For this study, the concept helps uncover economic rationalities and dependencies of actors at the local level, as moral economic understandings highlight examples for activities of economic agents that result from economic constraints and social coercion. In the case I present here, such coercions and constraints lie in an increasingly modern and industrialized cotton production that has been promoted through Indian government policies, the agro-scientific establishment, and favorable market conditions, which has encouraged farmers to turn toward a more entrepreneurial agricultural logic of intensifying modernization, incentivized for example through input-heavy cotton (Stone and Flachs 2017; Flachs and Stone 2018). This mindset rejects traditional farming practices, as these are regarded as "backward", and is instead oriented toward capital- and input-intensive farming practices (ibid.). I argue that this political economic context coined by technological change has created a dysfunctional learning environment for farmers, in which their agricultural and economic decision-making processes are more susceptible to external influences and increasingly subject to agricultural deskilling (Stone 2007; Stone and Flachs 2017). Against this backdrop, classical theorizations of moral economy concerning collaborative long-term consequences come into play, as is exemplified by means of the classical game theoretic prisoner's dilemma (Diekmann 2013). In this sociological allegory, the behavior of individuals can lead to devastating results for the collective (Diekmann 2013). In the presented case, the entrepreneurial rationale led individual farmers to turn toward agrarian rationalities that favor short-term profit maximization while collectively undermining the longevity of Bt cotton technology.

3.4 Hegemony in agri-food regime analysis

Hegemonic considerations are essential for a holistic contextualization of the political economy of agri-food systems. While the concept of agri-food regimes as developed by Friedmann and McMichael (1989; see also McMichael 2009), has contributed to understanding the emergence of agri-food regimes in the history of global capitalist processes, because it has linked agri-food systems to cycles of global capital accumulation, it has recently been criticized as insufficiently addressing hegemonic mechanisms of consent and coercion as described by Gramscian hegemonic approaches (Gramsci 1971; Jakobsen 2018b, 2021; Brown 2019). For the most part, agri-food regime analysis has centered on the contradictory and conflictual social forces that constitute the internal structure of agri-food regimes, largely built upon geopolitical conditions (Friedmann and McMichael 1989; Brown 2019). These opposing social forces characterize and constitute evolving agri-food regimes while at the same time providing a dynamism to the regime that challenges its stability and hence leads to new developments and transitions in the composition of global agri-food regimes (ibid.).

For the first agri-food regime, Friedmann and McMichael (1989) describe a global agri-food regime in which the British colonial movement, aimed at importing agricultural commodities from colonies and exporting manufactured goods from European metropoles, is juxtaposed by anticolonial countermovements. The second agri-food regime is then sketched out to have evolved around U.S. imperialist aspirations that intended to establish an international trade regime for agricultural products with postcolonial states, in which increasingly autonomous agribusinesses epitomized a countermovement that challenged such endeavors by undermining national economic boundaries. As the third and current agri-food regime, Friedmann and McMichael (1989; see also McMichael 2009; Brown 2019) describe a neoliberal corporate agri-food regime in which the contradictory forces are particularly strong, resulting in unstable social dynamics. The juxtaposition of social forces in the third agri-food regime as indicated by classical agri-food regime analysis is that of a binary agribusiness versus smallholder perspective (McMichael 2009, 2013; Bernstein 2016; Jakobsen 2018a). Especially smallholders of the Global South have been “either excluded from or unfavorably incorporated within the corporate food regime” (Brown 2019, p. 190), which is characterized by negative social and environmental impacts. Processes like the deregulation of markets which exposes farmers in developing countries to price volatility while protecting those in developed countries, or the devaluing of resources such as food and land in their social and nutritional quality into commodities and profit opportunities for investors with devastating effects on local agroecosystems, are considered to be the causes for the above-mentioned negative effects. In this binary perception of opposing dynamics in the current agri-food regime, smallholders are positioned as a “historical subject”, similar to the proletariat in Marxist conceptions of capitalist systems (Brown 2019).

However, this binary perception in classical agri-food regime analysis has recently been criticized for suggesting a misleading understanding of a homogenous peasantry and hence overemphasizing acts of resistance of smallholders to agri-food regimes (Otero 2012; Bernstein 2016; Jakobsen 2018a, 2018b, 2021; Brown 2019). The need to establish a more nuanced picture of the formation and stabilization of agri-food regimes is therefore highlighted in the recent literature (ibid.). As Brown (2019) argues, grand acts of resistance and outright rejection of agri-food regime principles are exceptions, whereas the more ‘normal’ scenario involves elite dominance and subaltern acceptance. Recent considerations of hegemony in agri-food regimes therefore build upon Gramscian approaches of hegemony, which go beyond the focus on conflict and contradictions in hegemonic regimes, and instead address questions of how evolved hegemonic structures endure, and explore how internal acquiescence is achieved within a prevalent regime (Jakobsen 2018a, 2018b; Brown 2019).

Here, the mechanisms of consent and coercion are of particular importance as, according to Gramsci (1971, p. 180; cf. Simon 2015; Brown 2019), a class gains and maintains hegemonic power through a combination of coercion of and obtained consent from the subordinate classes. From a Gramscian analytic perspective, emphasis is thus placed on the mechanisms dominant groups employ to produce and reproduce their ruling position over subaltern groups, even if the functioning principles of the prevalent regime work against them (Schnurr 2013; Brown 2019).

Gramsci (1971, p. 180f.) sees a crucial point in the ruling class to direct the interests of subordinate groups such that they are aligned with its own interests. Congruously, he perceives a local mediation through a rural elite as decisive for the need to win consent from the larger society with core agri-food regime principles (Brown 2019, p. 192). Such local actors then produce stability within the regime by providing local consent and enforcing coercion (ibid.). Intermediate classes hence play a key role in the reproduction of hegemonic ruling positions, as “hegemony is rarely commanded by a single class that acts unilaterally” (Brown 2019, p. 192), but needs a collaborative system of alliances (cf. Simon 2015, p. 19).

Overall, this act of obtaining consent must be backed by a supportive state apparatus, which provides the necessary modes of governance so that the industry can continue to proceed in a self-serving accumulating regime (Jakobsen 2018b; Brown 2019). As Jakobsen (2018b, p. 2) argues for the current neoliberal Indian agri-food regime, the state is partaking in “a hegemonic process of neoliberalising India’s agro-food system, with accompanying marginalising effects on broad sections of the rural population”.

Aligning with this recent criticism on the shortfalls of classical agri-food regime considerations, this research investigates hegemonic structures in the current Indian biotechnology-driven cotton regime from a Gramscian perspective and aims to be attentive to the heterogenous character of the Bt cotton-farming complex in Telangana. In doing so, this research provides a critical account of a state-industry complex that provides ground for the rural elite to profit from the current accumulation regime, coined by corporate hegemony. I argue that the neoliberal agri-food regime in India is reproduced through the implementation of Bt technology, as this favors established powers within the regime and thus eventually contributes to increased accumulation for national and international seed corporations on the one hand, and a rural elite of large-scale farmers, money lenders, and landlords on the other.

3.5 The economic sociology of imagined futures

Following Beckert (2013a, p. 323), who claims that "economic sociology can provide a microfoundation for political economy", this research draws upon understandings generated in economic sociology, in addition to moral economic considerations, in order to re-embed the broader political economic context and translate it to economic action on site. As Beckert (2013a, p. 323) argues, political economy focuses largely on macro phenomena, e.g., the explanation of capitalist dynamics at large, whereas "economic sociology focuses on the embeddedness of economic action" and thus serves as a 'sociological microfoundation' for investigating economic decision-making processes of relevant actors. He outlines that the expectations of such economic agents regarding their imagined future states of the world should be in focus (Beckert, p. 2013a).

As decision situations in economic contexts are marked by fundamental uncertainty, imagined futures help overcome much of the uncertainty in economic situations by outlining possible trajectories for future outcomes (ibid.). Beckert (2013b, 2018) therefore argues that imagined futures constitute the driving force of capitalism by rendering cognitive resources for identifying new potentials for capital accumulation accessible. In this cognitive process, the imagined futures of involved actors are paralleled by their fictional expectations and interest-driven narratives.

Since the details and events of the future can never be fully anticipated or calculated, Beckert outlines that actors build upon fictions about possible future states to draw conclusions in their decision-making processes. These fictions must be rather broad to allow room for maneuvering and creativity, but at the same time, they must be "plausible enough that [they] could become true" (Esposito 2007, p. 13). Fundamentally, imagined futures serve to dispend disbelief and equip economic actors with a perpetual capability to overcome paralysis and act purposefully despite omnipresent uncertainty about future events (Beckert 2013b, p. 226; Beckert and Bronk 2019, p. 8). By taking the shape of imaginaries of some future state of the world that is cognitively accessible in the present, these fictions motivate actors to develop innovations that, in turn, continually reproduce the capitalist system (Beckert 2013b).

The mental representations of the imagined future states accessible to actors are referred to by Beckert (2013b, 2018) as "fictional expectations". They are fictional in the sense that they represent potential future states *as if* those states were being realized (Beckert and Bronk 2019). While these expectations differ from literary fiction in their scope and ramifications, they are likewise anchored in specific narratives (Beckert 2013b; Beckert and Bronk 2019) that render them tangible to initiators and believers alike, structure their expectations, and create incentives for them to act purposefully. In this way, fictional expectations are at the core of macroeconomic dynamics; they create motifs for action in a constantly uncertain economic decision-making environment and enable relevant actors to engage in economic processes, which are potentially profitable but ultimately remain incalculable (Beckert 2013a). Beckert (2013a, p. 323) thus argues that the management of these contingent fictional expectations, and the institutional, political, and cultural foundations they rest upon, is "a crucial element of economic activity".

Fictional expectations published by state agencies or private corporations and firms, e.g., in the form of strategy papers or financial development forecasts, can thus be read as signals for economic actors that create an atmosphere of security for investments and for research and development activities (Beckert 2013b). Conversely, such fictional expectations, e.g., by guiding innovation processes, help creating future states that were hitherto only imagined (Jasanoff and Kim 2009, 2013; Jasanoff 2015). This aspect of rationalities that are embedded in economic sociology and provide actors with orientation in economic decision-making processes thereby helps them to navigate through the prevalent uncertainty that generally characterizes economic situations.

3.6 Policy assemblages, mobilities, and mutations

The body of literature engaged with *policy assemblages, mobilities, and mutations* emerged from the disciplines of political science, economic geography and STS (Peck and Theodore 2010; McCann 2011; Peck 2011; Cochrane and Ward 2012; McCann and Ward 2013; Stone 2012, 2017; Prince 2017) and builds upon and extends the notion of policy transfer and diffusion (e.g., Dobbin et al. 2007). The concept of *policy transfer and diffusion* is rooted in orthodox political science but is an "intrinsically geographical" approach (Peck 2011, p. 774; McCann and Ward 2013). The idea of policy transfer boasts difficulties from a geographical perspective and has thus faced increasing criticism (Peck 2011; McCann and Ward 2013; Prince 2017). It is claimed to lack attentiveness to the complexity of policy translation nexuses, as it relies upon the presumption of a linear and straightforward transferability of intact policy models, usually in the form of best practices, by presupposing an underlying rationality of involved decision-makers (Peck and Theodore 2010; Peck 2011; McCann and Ward 2013; Stone 2017). Resultingly, it fails to consider the relational dynamics of policy-making and neglects the possibility of policy modification, transformation or failure (Peck and Theodore 2010; Peck 2011; Stone 2012). Moreover, it assumes a voluntaristic policy learning model and does not take coerced transfers into account (Peck 2011; Stone 2012). It is therefore unable to do justice to messy interpretative realities and falls short to address political interests or asymmetrical power relations (Peck and Theodore 2010; Peck 2011; Stone 2012).

Both inspired by and aiming to address these criticisms, the approach of *policy assemblages, mobilities, and mutations* has emerged from an interdisciplinary field of critical policy studies (Peck 2011; Peck and Theodore 2010; McCann and Ward 2013; Prince 2017; Savage 2020). This approach is "attentive to the *constitutive* sociospatial context of policy-making activities" (Peck 2011, p. 774, emphasis in original; Peck and Theodore 2010; McCann and Ward 2013). It recognizes that policies can hardly be transferred directly and linearly, and that policy formation and transformation has to be understood as social, relational and territorial, being constituted by predominant power relations (Peck and Theodore 2010; Cochrane and Ward 2012). The idea of policy mobility and mutation, rather than transfer, entails the notion of a more dynamic, complex, and power-laden constitution of policy translation processes and networks, which "involves a wide range of practices and sites" (McCann and Ward 2013, p. 9). It is emphasized that policies morph and mutate throughout their journeys, do not arrive as complete packages, but instead "move in bits and pieces" (Peck and Theodore 2010, p. 170; cf. McCann and Ward 2013; Prince 2017). As the interpretation and reinterpretation of policies by all actors involved in the nexus is inevitably part of the translation process of policy mobilities, policies are always reshaped (McCann and Ward 2013). Congruously, according to Stone (2017, p. 2), in the process of translation "something is either lost, or learnt". Against this background of policy mutation, the new generation of policy studies moves beyond the examination of best practice transfer and extends its focus to policy failure mobilities in terms of "learning what not to do" (negative lesson drawing, worst practice policies) (Stone 2017, p. 1).

Policy translation therefore not only encompasses "straight-forward copying of policy" but rather a broad spectrum of objects and modalities of transfer (Stone 2017, p. 4; see also Stone 2012). The resulting spectrum of policy adaptation underlines the active construction and reassembling of policies and their implementation through policy actors on a local level (McCann and Ward 2013; Prince 2017; Stone 2017). These actors "not only actively [produce], but also actively [circulate] and [feed] back [policies] through global networks" (Cochrane and Ward 2012, p. 6). Policies are thus constantly remade throughout the process of mobilization and on the local site of adoption (Peck 2011; McCann and Wad 2013).

Policies are not only locally shaped, but they themselves shape places in turn (McCann and Ward 2013). Peck and Theodore (2010, p. 170) emphasize that “mobile policies, then, are not simply traveling across a landscape – they are remaking this landscape” and thus argue that “all policies are local” (cf. Stone 2017; Prince 2017). Cochrane and Ward (2012, p. 4) provide reasoning as to why this “localization” occurs: policies cannot be transferred straight from a to b “because they emerged from and are responses to particular “local” sets of social and political conditions which are not replicated in the places to which they are transplanted”. Policy mobility approaches therefore stress that context matters as “policy regimes and landscapes are more than empty spaces” (Peck 2011, p. 775). Policy translation is thus a matter of territoriality as well as relationality (Cochrane and Ward 2012, p. 7).

This post-transfer conceptualization of mobility and mutation has lately been fruitfully stimulated by concepts of policy assemblage which originate from Deleuze and Guattari (1987) and are related to Latour’s (2005) actor-network theory (ANT) (Latour 2005)[18] (McCann and Ward 2013; Prince 2017; Savage 2020). The notion of policy mobilities is thus closely linked to STS conceptions and “can find conceptual fertility through an engagement with STS, encompassing but also extending beyond [ANT]” (Temenos and McCann 2013, p. 353; cf. Jasanoff 1999). As both policy mobilities as well as STS are concerned with the “’mundane’ practices of policy-making under the rubric of ‘scientific knowledge’”, a combination of the two approaches has the potential to allow for a deeper investigation of policy mobility-related politics and legitimation strategies (Temenos and McCann 2013, p. 353).

The approach of *policy assemblages, mobilities, and mutations* views policy translation as an actively constituted rather than statically arranged ensemble that is relationally assembled through practices, and stresses the perspective of spatiality when studying such ensembles (McCann and Ward 2013; Prince 2017; Savage 2020). As such, it helps to “think policy mobility beyond the local-global binary” and instead argues that the global and the local are produced in the (policy) assemblage (Prince 2017, p. 336; cf. Keck 2019). As Temenos and McCann (2013) outline, the conception of policy mobilities as constituted in assemblages – a notion that likewise originates from STS (and is at times referred to as ‘agencement’ or ‘actor-networks’; cf. Callon 2007; Temenos and McCann 2013) – hence exposes the relational character of policy mobilities.

[18] Methodologically, for example, the Latourian ‘follow the thing’ from ANT approaches has been adapted to policy studies in the form of ‘follow the policy’ (Peck and Theodore 2012).

4 Research methods and area

This chapter provides an overview of the methodological approaches, the applied research methods and techniques, as well as methodological limitations of the study. Also, the research area will be presented.

4.1 Exploratory mixed-methods research design

Throughout the course of my research, I applied an exploratory mixed methods approach, in which I adapted the research method to the respective level under investigation (cf. fig. 1). Like my conceptual approach, I thus expanded my methodological approach throughout the research process from a narrower qualitative perspective to a broader quantitative perspective in alignment with the empirical and conceptual shift in focus. The initially applied qualitative research methods helped me to dive into the topic and gain first on-site insights in order to set the focus for my research, while the quantitative methods applied afterwards complemented the first findings from a quantifiable perspective, and thus helped me to facilitate schematization and allow for deductions on a broader scale in order to expand my point of view. Subsequently, I employed different research methods in the form of document analysis and expert interviews in order to re-embed the schematized findings into their broader context. For this, the combination of research methods and techniques of data acquisition and analysis turned out valuable. Overall, I used varying qualitative and quantitative techniques of data collection, which then enabled respective techniques of data analysis that finally led to a differentiated data analysis. In the end, this exploratory mixed methods approach proved beneficial, as it helped me to rearrange my research focus when necessary and put my findings into perspective.

4.2 Qualitative social research

The primary research focus on the rural socio-economic effects of Bt technology implementation on Bt cotton-farming household livelihoods required a qualitative research approach. By first employing qualitative research methods, I was able to gain deep insights into the daily lives of Bt cotton farmers, experience their vulnerable dependency on crop success, and witness their despair in the case of a failed harvest. In this way, I received a profound understanding of the complexity of agrarian decision-making processes within choice-limited agricultural preconditions in rainfed neoliberal rural Indian contexts. In addition, I got a glimpse into the complex social relations and pressures on the site of the local nexus of Bt cotton production, involving not only farmers but also hired laborers, middlemen (commission agents), model farmers, cotton millers and ginners, seed producers, and other actors. These understandings could not have been achieved either through more thorough literature review, or through quantitative approaches. Speaking to farmers in qualitative guided interviews and informal conversations revealed the agrarian entanglements of the crop's biotechnological properties, uncertain meteorological conditions, the broader political and institutional frameworks, and the economic pressure on farming households to gain sufficient yields to provide for their living and repay debts, as well as their own aspirations to perform well.

While quantitative research methods aim to confirm and schematize already available data, qualitative research in contrast is more inductive and exploratory (Lamnek 2016; Flick et al. 2013b; Rosenthal 2018). The sample size is small and there is no real random sampling according to the principal of chance (Lamnek 2016). Therefore, the aim lies less in portraying an objective reality but rather in depicting subjectivity and individual problems. Qualitative research thus seeks to explore complex correlations and processes in detail for a thorough understanding. Only after the analysis of an individual case, the results are compared or generalized to other cases or "embedded into theoretical references" (Flick et al. 2013a, p. 106). Consequently, the research hypotheses are not necessarily determined ex ante, but are rather generated on the basis of the collected data leading to well-founded theories (Rothfuß and Dörfler 2013; Rosenthal 2018). Altogether, the approach is more flexible and explorative in character.

This proved beneficial in the course of my research, as it allowed me to shift my focus inductively during the process of qualitative data acquisition. While I originally aimed to address the new technology's effects on (non-)knowledge and decision-making processes in the farming households with a specific focus on gender relations, this original focus turned out unfruitful and was hence rejected. It turned out throughout the execution of the first few qualitative interviews that the re-occurrence of target pest populations in this area, was of higher relevance for the interviewed actors and promised to be more insightful for me as a researcher. At that time, however, the issue had not yet been taken up in the literature and had hence been unforeseeable prior to accessing the field, in spite of profound previous literature research. The higher research demand in this field exposed through the qualitative data collection thus drove me to adjust my focus inductively towards the more promising, and for the involved actors more relevant, area of research on the socio-economic effects of the implementation of Bt cotton technology, and the return of its target pest, on Indian smallholders.

During the fieldwork and in the course of the interview transcription that I usually carried out directly after the interviews, I further specified the research focus and adjusted it accordingly in the subsequent interviews and informal conversations. In this context, information that revealed controversies was followed up whereas repetitive information was interpreted as a saturation of a specific topic from which I hence withdrew the focus. The applied qualitative data collection techniques included guided and expert interviews, participatory observation, informal conversations, and document analysis.

4.3 Quantitative social research

All above-mentioned techniques of qualitative data collection allowed for a very detailed but also narrow focus on the socio-economic effects of the implementation of Bt technology on Bt cotton-farming households' livelihoods and their altered vulnerability contexts. In the course of this qualitative research, the research focus shifted to the exploration of the broader political economic implications of Bt cotton implementation. Thus, calling for a wider methodological research approach, I subsequently employed quantitative research methods.

I applied the quantitative methods in order to build upon the previous results based on the findings revealed through the qualitative research methods mentioned above. While the qualitative findings revealed the extent of the altered vulnerability contexts of Bt cotton-farming households, the combination of qualitative and quantitative research methods aimed to link these local vulnerability contexts of Bt cotton-farming households in rural India to the wider political economic contexts and hence intended to embed them within their expanded nexus of Bt cotton production in India and beyond. This procedure enabled me to compare and confirm the prior qualitative findings and investigate their degree of significance on a broader scale compared to an individual or local scale. Within geographical research, the combination of qualitative and quantitative methods has become more common, as they can be used complementarily and thus allow for the reassurance and triangulation of resultant findings (Reuber and Pfaffenbach 2005; Flick 2013).

While the qualitative research methods were employed to gain first deep but individual insights, the employed quantitative methods then served to provide more general but representative findings, allowing for schematization and deductions on a wider scope. These quantitative findings hence served to gather “hard data” (Reuber and Pfaffenbach 2005, p. 34; see also Mattissek et al. 2013) that could later be scrutinized for geographical, social, economic, and other patterns, incongruities, and statistical outliers.

To cover as broad a spectrum as possible, the quantitative research technique that was employed for this study was a representative survey among Bt cotton-farming households in the three highest-ranking districts in regard to total cotton area, percentage of area under cotton to total area sown, and outturn in Telangana, India. This was followed by varying univariate, bivariate, and multivariate statistical analyses.

4.4 Research area

In order to answer the central questions of this thesis, the case studies compiling this research explicitly focus on the Indian state of Telangana, whereas other cotton-producing states of the country are not taken into consideration. Telangana was chosen due to its high-ranking position among Indian cotton-producing states, as it ranks third after Gujarat and Maharashtra with regard to cotton area and production (Cotton Corporation of India (CCI) 2018). In the 2016/17 season, the area under cotton cultivation in the state was 1.4 Mha, and production reached 4.8 million bales, with a yield of 579 kg/ha (CCI 2018, p. 3). Located in the southern zone of Indian cotton production, Telangana’s cotton cultivation primarily takes place under rainfed conditions (Gaurav and Mishra 2012; Choudhary and Gaur 2015). As the effects of Bt cotton are particularly contested for non-irrigated areas of cotton cultivation (Gutierrez et al. 2015; Gutierrez 2018), in contrast to profiting northern irrigated Bt cotton growing states, the state provides a valid perspective of southeastern Indian rainfed cotton production.

As the research methods for the two research visits, conducted in August and September 2018 and 2019, differed, the field approaches varied accordingly. While for the first field stay, I followed an exploratory and therefore non-representative qualitative research design, for the second field stay, representativity had to be ensured for the quantitative survey, as this required an approach that was randomized and therefore fixed from the outset. The two research stays also differed in that during the first stay, I was new to the field and thus relied upon the project’s cooperation partners from the University of Hyderabad and the Loyola academy in Secunderabad, who facilitated the access to the field.

In total, for the first research visit, the project team that consisted of the PI, two translators, and myself in the position as doctoral researcher, examined three selected sample sites in Karimnagar district for data collection in August and September 2018. We chose to conduct the first phase of data acquisition in Karimnagar district as study region, because it is one of the state’s major cotton-producing districts and neighboring districts had already been the subject of previous studies related to Bt cotton (Stone 2011; Stone and Flachs 2015; Kaviraju et al. 2018; Kukanur et al. 2018). These earlier studies provided context and a basis for comparison in identifying recent changes in the impact of Bt cotton technology on farmers' livelihoods. The sample villages were then selected based on the criterion of most area under cotton according to the local knowledge of our colleagues from the Department of Agricultural Science and Rural Development of the Loyola academy in Secunderabad. We were then given the possibility to accompany some of our colleague’s students who were completing a practical training at local (cotton and other) farms, which facilitated the first access to the field, whereas the subsequent access could be established via snowball sampling (village 1; cf. fig. 7). In the first study village, one interview partner (the local cotton miller) informed us about a neighboring village involved in cotton production, which then became our second study village (village 2; cf. fig. 7). The third study village was again selected based on the criterion of agricultural area under cotton (village 3; cf. fig. 7; cf. Appendix 2, Table 1 for a full list of interview partners). The field access to the third study village was established through a local seed shop owner. The geographical distance to the first two sample villages was beneficial, as this provided a counterpoise in the spatial focus.

For the survey conducted during the second field visit in August and September 2019, the project team consisted of the PI, a student assistant, six translators and survey assistants, and myself as a doctoral researcher. We randomly selected 15 sample villages beforehand in the three major cotton-producing districts of Telangana: Adilabad, Warangal, and Nalgonda (cf. fig. 7). These three districts were chosen because they ranked highest in the criteria total cotton area, percentage of area under cotton to total area sown, and outturn (Government of Telangana 2017, p. 118-120)[19]. For each of the three districts, we selected three *mandals*[20] according to their share of agricultural area under cotton. We received the relevant data from the respective agricultural offices in the districts (Agricultural Office Adilabad 2014; Agricultural Office Nalgonda 2015; Agricultural Office Warangal 2014). Then, via automated computerized sampling, we randomly selected five villages in the range of 1,000 to 6,000 inhabitants on the basis of available population data from 2011 and calculated the respective sample sizes per village[21] (cf. Appendix 4, Table 2) (Government of India 2011).

[19] Since no other data were available at the time of our survey, all the data used in the sampling procedure refer to the erstwhile districts and village structures of Telangana before they were restructured in 2016.

[20] A mandal is the administrative division subordinate to a district.

[21] Our sampling procedure rests on population figures presented in the 2011 census. These figures might deviate from actual proportions, as recent population dynamics may have resulted in changes in some of the village sizes.

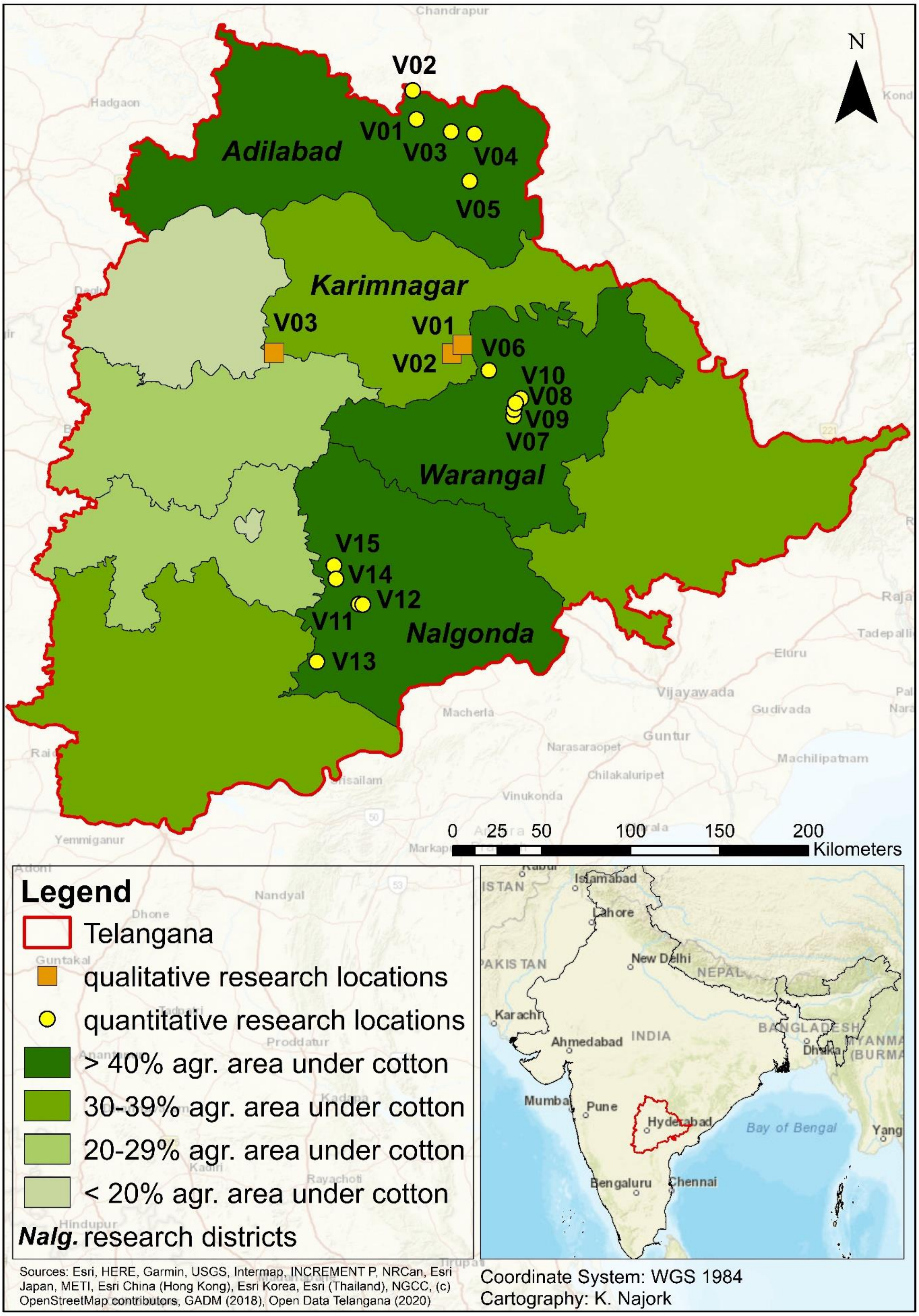

Figure 7: Research area

4.5 Data acquisition

Throughout my research, I followed an exploratory procedure that roughly led me from qualitative to quantitative approaches. This proceeding proved helpful in moving from a narrower empirical and conceptual focus on the socio-economic impacts of Bt cotton on a household level to the larger implications of Bt cotton implementation. Thus, the qualitative methods proved fruitful in making me understand the farmers' individual perspectives, their entanglements in the nexus of Indian rural Bt cotton production and their limited agricultural choice resulting from this. Not least, they made me aware of the severity of a lost harvest due to pest infestation. The quantitative survey applied afterwards helped me to "zoom out" again and widen my perspective in regard to content and area, and thus helped to put the qualitative findings into perspective by comparing and schematizing them.

Overall, I used the following techniques of qualitative research: guided interviews, expert interviews, participatory observation and informal conversations, as well as a document analysis that was conducted after the field visits. In addition, together with the project team, I conducted a quantitative survey. These applied techniques will be outlined in detail in the following.

In total, 55 qualitative interviews and 457 quantitative survey interviews were conducted within the research. Of the 55 qualitative interviews, 42 interviews were problem-centered interviews conducted mainly with Bt cotton farmers but also with other actors directly involved in the production of Bt cotton, such as one cotton miller, two input shop owners, and one commission agent who was actively involved in cotton trade with farmers (cf. Appendix 2, Table 1). The remaining 13 interviews were expert interviews conducted with top ranking entrepreneurs, politicians, and activists (cf. Appendix 6, Table 3). The 457 quantitative interviews were all conducted with Bt cotton-farming household heads within a single survey (cf. Appendix 4, Table 2).

4.5.1 Guided interviews

In the exploratory research design followed in this study, guided interviews were chosen as the main and initial data collection technique and thus provided the data basis for the subsequent research (cf. fig. 1). Due to its high degree of flexibility, this qualitative research method is considered particularly suitable for exploratory studies (Beller 2016; Schnell et al. 2013).

Guided interviews are categorized as a semi-structured interview type, as they rely on an interview guide which contains the relevant thematic complexes and questions but is not considered as fixed, neither in its content nor in its order (Hopf 2013; Mattissek et al. 2013; Lamnek 2016). As the interview guide is based on the interviewer's previous knowledge and preliminary considerations obtained through a thorough literature research, it requires a deductive preparation by the researcher (Schnell et al. 2013; Lamnek 2016). This a priori preparation is owed to the problem orientation of this method. The focus on a specific issue or problem that is determined before the acquisition of empiric data, requires, at least to some extent, a theoretical preparation on the interviewer’s part (Mattissek et al. 2013; Lamnek 2016). This deductive character is then complemented by inductive and exploratory elements, as it takes the respondent’s subjective perspective into account (Hopf 2013; Reichertz 2013; Kuckartz 2014). Resultingly, the interview guide is open to changes throughout the empirical research phase, both overall and during each individual interview situation. It hence allows for the combination of predetermined questions and open conversation and enables the researcher to react flexibly to the interviewee, e.g., by asking ad-hoc questions or changing the order or the number of the questions in the guide (Longhurst 2010; Lamnek 2016). It is therefore the specific interview situation, i.e., the interview partner and the course of the conversation, that determines which questions are actually asked and in which order, while the interview guide rather serves as a framework of orientation and memory aid for the interviewer (Dunn 2010; Schnell et al. 2013). This adds to the natural atmosphere of the interview situation and in turn creates a relationship of trust between interviewer and interviewee (Lamnek 2016). Moreover, this combination of interview guide and spontaneous conversation ensures that all important areas of research are covered while allowing interviewees to choose a focus in a specific (sub)topic that is most important to them (Desai and Potter 2006). As is typical for qualitative research, the questions formulated for the guide are usually open questions that are used context-dependently as to allow open conversation (Mattissek et al. 2013; Lamnek 2016).

4.5.1.1 Local problem-centered interviews

All 42 problem-centered interviews were conducted on local sites of Bt cotton production in the Karimnagar district in Telangana (cf. fig. 7). These problem-centered interviews were conducted in August and September 2018, and thus in the cotton season of 2018/19. They comprised mainly Bt cotton farmers, but also other actors involved in the production of Bt cotton, including two owners of shops selling inputs (for fertilizer, pesticides, seeds, and so forth), one owner of a mid-sized cotton mill, one coordinator of a local branch of the governmental extension service (*Krishi Vigyan Kendra*, KVK), one commission agent active in cotton trade, one representative of an Indian seed company, and one head of a village council (*sarpanch*) (cf. Appendix 2, Table 1). All interviews were conducted by a research team consisting of the project’s PI, two interpreters who were fluent in English, Hindi, and Telugu, and myself in the position as doctoral researcher.

Within the selected villages (cf. chapter 4.4), we mainly found interview partners by means of random walks. We scheduled these random walks for early morning and late afternoon so as not to disrupt the farmers' work schedules, so that they would be available in the villages and we would not waste their valuable work time. In this way, farmers easily volunteered and, if they were involved in cotton production, were usually interviewed at their homes to create an atmosphere of trust. The other, non-farming interview partners were specifically selected and targeted at their work places (seed shops, cotton mill, KVK office, cotton market). This sampling process allowed for a more diversified group of interviewees in terms of farming characteristics and socio-economic biases than snowball sampling alone.

The interview duration was usually around one hour, but farmers' and other actors' time-related restrictions were respected and hence interviews shortened if this was desired. The farmer interviews were conducted in Telugu and the answers were immediately translated to English to enable the interviewer to react to the interviewees' responses and adapt the subsequent question if necessary. Most interviews with other actors were carried out in the same manner, as only few interview partners spoke English. All interviews were recorded in agreement with the interview partners, except for one interview with a representative of an Indian seed company, as this interview was conducted in the cotton field and ginning mill, where the recording was obstructive. It was therefore recorded from memory by the research team immediately afterwards. Additionally, I took field notes during each interview so as to ensure completeness of the questions listed in the interview guide and to add additional questions that arose from the interviewees' responses.

Our two interpreters were especially helpful, as they not only helped us to overcome the language barrier, but furthermore gave us advice in local habits and codes of conduct, and assisted us in accessing the local village councils (*gram panchayat*). The mediation of the two interpreters was helpful during the interview situation itself, but also afterwards, when we discussed the interviews we had just conducted with them. This helped us to address open questions resulting from the interviews and follow up on Indian specific customs or regulations and improved our overall understanding of specific contexts. The reflection on our conducted interviews became part of our daily schedule, which routinized the clarification of potential misunderstandings, the identification of newly emerging areas of interest, the adaption of our research questions as a whole, as well as specific interview questions.

The semi-structured interview guide was conceptualized in accordance with the livelihood approach (cf. chapter 3.2) and was translated and discussed in close consultation with one of the two interpreters to ensure that it was comprehensible and appropriate in the cultural context. This allowed to jointly reflect on topics a priori and adjust questions accordingly where necessary. Apart from an introductory overview section with some closed-ended questions, the questionnaire contained mainly open-ended questions. Thematic focuses covered farmers' direct household livelihood situations, agriculture, vulnerability and shocks, their overall evaluation of Bt cotton, and questions related to knowledge and learning. The interview guide varied from interview situation to interview situation and was never exactly the same, as is typical for guided interviews. The continuous adjustment of our research and guided questions firstly enabled us to react to specific interview partners and situations, and secondly allowed us to update our interview guide based on new empirical findings. While I initially focused on general agricultural and gender-related decision-making processes at the beginning of the empirical research, I quickly shifted focus to PBW-related questions concerning livelihoods and vulnerability. I made further but less extensive adaptions throughout the remaining fieldwork phase as I focused more on Bt cotton production in the early empirical stages, whereas this later shifted more towards questions related to Bt cotton sale and diffusion.

4.5.1.2 Expert interviews

Apart from the 42 problem-centered interviews, within the research project, 13 expert interviews were conducted by the PI and a former doctoral researcher of the project in September 2017 (two preparatory interviews), and February and March 2018 (11 Interviews) with political parties, farmers' associations, and industrial, business, trade, and environmental associations involved in the Indian Bt technology controversy. The interviews were conducted in Hyderabad and Delhi, and the interview partners were found through online research, with the aim of mapping the Indian debate on GE crops and hence according to the criterion of integrating and representing diverse perspectives on this debate. Thus, a variety of top ranking entrepreneurs, politicians, and activists were interviewed, which included, for example, a managing director of the agricultural biotechnology company Metahelix Life Sciences and member of the Association of Biotechnology Led Enterprises (ABLE), the director of the South Asia Biotechnology Center (SABC), the NGO activist and founder of Gene Campaign, Dr Suman Sahai, as well as the former minister of Environment and Forestry, Jairam Ramesh, who imposed a much-debated moratorium on Bt brinjal[22] in 2010. The interviews were conducted in English by the PI and the project's former doctoral researcher without translators and were transcribed afterwards by student assistants, including myself, under the supervision of the former doctoral researcher.

Expert interviews are a subcategory of the guided interview and are regarded as particularly suitable for obtaining targeted information, as the interview partners are ascribed the status of being experts in the field (Hug and Poscheschnik 2010; Lamnek 2016). Experts are persons

[22] Bt brinjal refers to the GE variant of eggplant. While authorized in the neighboring Bangladesh, India has not (yet) legalized this GE food crop. It was intended to be authorized by the responsible authorities (GEAC), but this decision was overruled by the MoEF under the leadership of the then minister of Environment and Forestry, Jairam Ramesh, who imposed a moratorium on the commercialization of the crop in 2010 (Choudhary et al. 2014). Until today, this moratorium is active and fiercely debated.

who deal intensively with a subject in a professional or voluntary capacity, and thus have in-depth knowledge and experience in the issue under investigation, a specific field of action, or professional experience (Meier Kruker and Rauh 2016).

As the data acquisition in the form of expert interviews preceded the interviewing of farmers on site, it set the stage for subsequent research by covering a wide range of knowledge areas related to the field of Bt cotton research, production, and related policies in India. By interviewing various experts involved in the nexus of Bt cotton production, a solid knowledge base was established, upon which other field data collection techniques could be effectively applied. The data analysis of these interviews, however, was undertaken subsequent to the analysis of the local problem-centered interviews with actors involved in the production of Bt cotton. This proceeding was owed to the fact that, while the previously conducted expert interviews provided an expanded knowledge base on the topic, the problem-centered on-site interviews allowed for a more specific and detailed entry-level perspective. By starting the analysis from a narrower angle and only subsequently expanding the focus, the analysis of the overall data set could be approached heuristically and complementing information could be linked in a meaningful way.

4.5.2 Survey

The qualitative empirical research was followed by a complementary quantitative empirical research phase in the form of a representative survey (n=457) in August and September 2019. The outline of this quantitative research was based on the findings of the previously conducted qualitative research of the first empirical fieldwork phases, which hence served as vantage point for the subsequent representative survey. The latter method therefore aimed to complement the prior findings from a quantifiable perspective in order to facilitate schematization and enable deductions on a broader scale.

As this aim required guaranteed representativity, the randomization as well as standardization of the interview situation and related aspects needed to be ensured (Schnell et al. 2013). This includes the standardization of the number, order, and formulation of interview questions, the method of accessing the field and contacting the respondents, and finally the analysis of the data (ibid.). In consequence, the quantitative survey method strongly deviates from qualitative interview methods due to the former’s higher degree of standardization (Schnell et al. 2013).

In order to ensure representativity for our survey, we therefore selected the target survey villages in accordance with standardized and randomized proceedings (cf. chapter 4.4; cf. Appendix 4, Table 2). On the village level, we further ensured randomization and standardization. For this, we defined the erstwhile boundaries of each village[23] in consultation with the head of the local village council (*sarpanch*) and then divided the village into commensurate areas on the basis of satellite images. This allowed us to take geographically replicated socio-economic backgrounds (e.g., caste or class) into account and aimed to avoid resulting biases. Within these commensurate areas, we identified the farming households for our survey interviews by means of random walks. Along these random walks, we targeted every other house and alternated starting at the village center or outskirts in order to avoid further potential biases resulting from geographically replicated socio-economic disparities. The 457 farming households were interviewed through their respective household heads, which resulted in inevitable sex- and agewise biases, since the vast majority of household heads were male and 30 years or older. The household heads were then individually interviewed in order to avoid distorting effects through neighbors or HH members. All interviewees had been growing cotton within the last five years.

For our quantitative survey, we, i.e., the project's PI, a student assistant, and myself as doctoral researcher, were accompanied by six surveyors from Hyderabad who were fluent in both English and Telugu and were thus responsible for data collection. They all received extensive training on the thematic focus of the study as well as on the quantitative methodology prior to beginning fieldwork. This also included test interview scenarios that the participants conducted among each other. This intensive preparatory phase allowed for a deep mutual understanding between the surveyors and the rest of the study team.

A pretest was conducted prior to the proper survey in two Warangal villages that were not included in the sample in order to ensure that the questions were well understood by the interviewees and to allow the adaption of those questions that were misleading. This also allowed us to test the proper handling of the questionnaire itself, as well as the respective hardware (tablets) and software (*LimeSurvey*) by the surveyors.

The questionnaire covered the thematic focuses of sociodemographic and agriculture-related data at the household level, as well as the cultivation of Bt cotton, PBW infestation, refuge crops, and access to knowledge and markets (cf. Appendix 3). The topics and the according questions were chosen based on the findings of the preceding qualitative interview methods and the resultant findings, and were adapted after the pretest to allow for an improved understanding of the questions. The questionnaire included open- and closed-ended questions and Likert-scale, single-choice, and multiple-choice questions. The number of questions per questionnaire varied due to a large number of conditional follow-up questions.

[23] As we relied on the decennially published Indian census data for our survey sampling method and, thus, used the 2011 census data for our sampling, it was inevitable that all the data used in the sampling procedure refer to the erstwhile districts and village structures of Telangana before they were restructured in 2016.

4.5.3 Participatory observation and informal conversations

While the qualitative research methods of participatory observation and informal conversations were not the main components of my empirical fieldwork, they were still applied where useful and as such provided a helpful addition to the main qualitative (guided interviews) and quantitative (survey) research methods. The scientific participatory observation in contrast to our observations in daily life is characterized by a systematic documentation and the object of observation in the form of the reconstruction of the intentions and reasons for action of the observed (Schnell et al. 2013; Lamnek 2016).

As such, the participatory observations of my qualitative empirical fieldwork enabled me to gain a deeper understanding of the significance of a successful cotton harvest for the farmers I interviewed for my research. Accompanying them to their fields allowed me to receive insights into the plant's as well as the insect's phenotype, and revealed the devastation of farmers who experienced a failed harvest. This made me painfully aware of the essentiality of the crop for Bt cotton-farming households' livelihoods and the pressure they face in regard to their agricultural performance. In this regard, informal conversations often addressed such affective and emotional areas of conversation that were sometimes overlooked in planned interview situations. These observations and informal conversations were usually documented in the form of field notes, which I took either directly or, if this was too disruptive for me or the addressee, following the situation.

I obtained insightful observations that were accompanied by informal conversations or informal interviews, for example as I joined a farmer in his cotton field, who not only showed me the plants, but also his irrigation facilities, as well as a sucking pest that had recently infested some of his cotton plants. Other insightful observations were made when I accompanied a representative of a local seed company, who informed us about the practice of manual pollination in the process of hybrid seed breeding and demonstrated the same in the company's cotton hybrid breeding fields. Moreover, in a local mid-sized cotton mill, we were shown the process of ginning, i.e., the deseeding of the cotton lint, the baling of cotton according to its quality, as well as cotton oil production and the resultant seed cakes that are used as fodder for cattle. This highlighted the complexity of the Bt cotton nexus, for example that the plant is not merely used for clothes but also as aliment for cattle and humans alike.

4.5.4 Document analysis

The above-mentioned fieldwork composed of both qualitative and quantitative methods was complemented by a remote document analysis. Due to the COVID-19 pandemic, no further empirical fieldwork could be conducted, so this method turned out to be a useful addition to complement the previous empirical data and findings. According to Bowen (2009, p. 27), document analysis is a “systematic procedure for reviewing or evaluating documents” that is often combined with other qualitative research methods in order to enable a triangulation of data. In this research, I combined the method of document analysis with previous qualitative and quantitative research methods. This allowed for an innovative composition of the data acquired in the subject area of refuge crop policies. In today's secularized societies, documents are gaining in importance due to the trend toward the juridification of all areas of life (Wolff 2013). However, while the written form of communication increases its reach, it jeopardizes the success of communication at the same time (ibid.). This failure of communication, in my research concerning the thematic area of refuge crop policies, could be exposed through such a document analysis. Enabling me to track specific alterations of refuge policies over time and across countries, the analysis proved fruitful for my research, as it gave me an overview of the deep-seated mistranslations of refuge policies and thereby provided a more nuanced perspective on the malfunctioning of Bt cotton refuge crop policies than the prevalent narrative of simple mismanagement by farmers. In this regard, the triangulation of the previously collected qualitative and quantitative data with the data collected by means of document analysis helped me to investigate incongruities between farmers’ cultivation behavior concerning the implementation of refuge crops and the underlying policy requirements. For this, I mostly analyzed policy papers authored by the GEAC from the time of the introduction of Bt cotton in India until today.

4.6 Data analysis

As I applied a mixed methods approach with qualitative and quantitative methods for this study, the approach to data analysis varied according to the methods chosen. The different processes of data analysis are outlined below.

4.6.1 Qualitative data analysis

Following the qualitative empirical phase, the conducted interviews, which were saved via audio medium (dictation device), were subsequently transcribed and conferred into written English[24] (Schnell et al. 2013; Lamnek 2016). Due to the fact that the transcribed English audio data was a translation from Telugu and was therefore not the exact wording of the interviewees, a literal transcription was renounced as this did not contribute to answering the research question. I usually started the transcription process on the same day I conducted the

[24] Only one interview with a representative from an Indian seed company (cf. Appendix 2, Table 1: T03-I01) was recorded from memory and from field notes by the research team immediately afterwards, as a recording was obstructive during the interview situation on the field and would have reduced the atmosphere of trust between the interviewers and interviewee.

interviews, which helped me to reflect again on the conversations, the interview situation itself, and newly emerging topics that could be integrated into the interview guide for the next day. The immediate transcriptions were hence useful to keep the interview guide updated and adjust it when necessary (cf. Appendix 1).

For the subsequent analysis of the collected data, which mostly included the transcribed interviews, but also field notes on observations and informal conversations, I chose the qualitative content analysis according to Mayring (2015; cf. Hug and Poscheschnik 2010; Mayring 2013; Kuckartz 2014). This method aims at a systematic and theory-led analysis of the collected data, usually in text form, but also in the form of other communication material (Mayring 2013). The systematization is ensured through strict and pre-formulated decoding rules following a categorization of the material. The material is structured according to specific, usually content-related criteria, which eventually results in a unique set of categories that constitute the decoding guide by means of which the data material is analyzed (Hug and Poscheschnik 2010). The process of structuring the material can be deductive or inductive, depending on the research question and the prior knowledge of the interviewee. This approach specifies the process of analysis and therefore increases the transparency and objectivity of the data processing. The available data material is then dissected in regard to the predetermined categories and specific aspects are filtered out (Hug and Poscheschnik 2010; Mayring 2013).

Mayring (2013) distinguishes between different forms of qualitative content analysis. Of these, the 'inductive', the 'structuring', and the 'explicating' techniques of content analysis were particularly relevant for my research. For the processing of the data collected during the expert interviews, I followed Mayring's (2013) 'inductive' categorizing approach, as the specific thematic focus of the findings was uncertain due to the exploratory research approach. Since this proceeding requires the prior summarizing of the material, this approach entailed the 'summarizing' content analysis (Mayring 2013). After summarizing the interview's sections into key words, categories were defined based on the quantity and significance emphasized by the interviewee.

In contrast to that, for the analysis of the problem-centered on-site interviews with farmers and other actors involved in the production of cotton, I followed a more 'structuring' content analysis technique (Mayring 2013), as I particularly focused on the deductive categories of the sustainable livelihood approach (cf. chapter 3.2). In this case, the deductive technique proved helpful to answer the previously determined research questions related to farmers' livelihoods. Moreover, this deductive categorization made the material more accessible to the reader by providing a clear structure for the analysis. Here, only the subcategories of the framework that were focused on for the analysis were inductively selected based on the interviewees' thematic focus. The categories and findings resulting from these analyses were later complemented by the ‘explicating’ analysis, which draws upon systematically collected additional material (e.g., document analysis, observations) in order to make incomprehensible text passages understandable and accessible (Mayring 2013).

4.6.2 Quantitative data analysis

The analysis of the quantitative data included various data processing techniques in the form of univariate, bivariate, and multivariate statistical analyses. For this, the data set firstly underwent randomized preparation and editing in order to ensure the targeted representative sample sizes among all selected villages (cf. Appendix 4, Table 2). The resulting data set was then coded so as to allow for computerized processing of the data using the statistical programs Excel and SPSS. After a thorough preparation of the data set, the necessary data analyses could be employed. Throughout the quantitative data analysis, I calculated varying measures regarding farmers’ sociodemographic and socio-economic household features, basic agricultural features, the impact of different agricultural problems including PBW infestation, and knowledge-related characteristics.

At first, I applied univariate descriptive analyses, as these are an important initial step in any data analysis. These fundamental analyses serve to detect possible errors in data collection and/or outliers in the data set and describe the data set on the basis of its individual characteristics. Univariate analyses aim to determine frequency distributions as well as position and dispersion measures (De Lange and Nipper 2018). In the case of my research, this included basic descriptive statistics in the form of averages, median values, maximum and minimum values, as well as quartiles and quantiles. This procedure proved useful to get a good overview of the data set and thus helped to figure out possible correlations between specific variables. These were analyzed in a next step.

The bivariate analyses then included calculations of correlations, which aimed to reveal potential relations of socio-economic household characteristics and agricultural features with the impact of PBW pest infestations and recent changes in agricultural production. For this, I examined the frequency distributions of all relevant variables by means of χ^2-tests, as well as cross-tables (De Lange and Nipper 2018). Where necessary and possible, I expanded categorical ranges to obtain sufficient values in the cross-tabulations. Otherwise, sparsely populated categories as well as variables with insufficient overall frequencies (cross-tables with > 20% of cells with expected counts below 5) were excluded. I quantified the identified correlations by Cramer’s V (φ) (nominal data; $p \leq \alpha \leq 0.05$) and Spearman’s rank (ρ) correlation (ordinal data; $p \leq \alpha \leq 0.05$) coefficients and studied them further on the basis of relevant cross-tabulations (De Lange and Nipper 2018).

I built upon these bivariate analyses to choose the most relevant variables for a multivariate cluster analysis. Based on this preparatory work, I conducted a two-step cluster analysis aimed to identify different farmer types in the Telangana cotton-farming community. This type of cluster analysis was chosen, as it allowed for the integration of varying scale levels and as it is commonly used in the geographic discipline (Fromm 2012; Kuß et al. 2018). Variables that negatively influenced the silhouette measure were externalized from the cluster analysis itself, but were kept as evaluation variables. As such, they had no direct influence on the cluster composition, but were still examined for correlations with the resultant cluster groups. While the cluster analysis involved the study of several possible group constellations, I chose the composition with the highest possible silhouette measure. The cluster groups were characterized by the variables with the highest predictor importance, as these mostly influenced the categorization of the clustered groups (cf. chapter 7.4.3). After having processed the cluster analysis, I tested the two resultant groups again for correlations with the key variables and evaluation variables.

For processing the quantitative data, it was particularly helpful to draw on the previously gathered and evaluated qualitative data for contextualization. Next to the initial univariate descriptive analyses, this previous knowledge facilitated the subsequent correlation analyses, as it provided indications as to where to look for potential correlations. The same applies for the cluster analysis, which relied on prior findings resultant from bivariate correlation analyses on the one hand, and qualitative data on the other, which helped me find the variables to focus on in the subsequent cluster analysis.

The quantitative data analysis was particularly challenging in regard to the handling of missing values. These missing values occurred in the data set due to entered values that were invalid, e.g., obviously transposed digits, and due to sensitive questions contained in the questionnaire, e.g., about loans that farmers may have taken up, which remained unanswered. While the practical handling of missing values remains controversial, as the imputation and non-imputation both inevitably result in data bias, it is usually argued that a non-imputation of values causes greater distortion in the data set (De Lange and Nipper 2018). Although I considered multiple imputation as the preferred method for dealing with missing values, in the end, I had to renounce the idea of imputing missing values altogether because it was not fit for my data set. Since the number of missing values per variable was either very low, allowing the less cumbersome method of omitting incomplete cases, or very high, and thus rendered the method of imputation impossible, the otherwise favored method of multiple imputation had to be ruled out.

4.7 Methodological limitations and reflections

While this study is diverse in regard to conceptual and methodological approaches, it encompasses limitations, too. These will be addressed and reflected upon in the following.
First, it must be mentioned that it is regrettable that the data acquisition took place during the same period of the cotton season both times. While this time frame was intentionally chosen, as it is within the plant's growth phase, a third field research scheduled for the period of seed purchasing during April and May (for the cotton season 2020/21), unfortunately had to be cancelled due to the COVID-19 pandemic. As this was intended to be the longest of all conducted field stays, this cancellation is particularly unfortunate, as now, the time dedicated to fieldwork in this study is rather short and more time in the field would have allowed for deeper immersion in the research environment.
Further limitations arose in the form of several biases that possibly occurred in the process of data gathering. Firstly, mainly relying on farmer recall, the gathered data likely underlies exaggeration, underestimation, and misremembering, particularly as for several questions, farmers were asked to consider past events and phenomena. Secondly, the gathered data was likely biased due to social desirability or even a sense of shame. In this regard, particularly questions with a higher degree of sensitivity, e.g., questions regarding indebtedness, or those involving illegal activities, such as the non-compliance with refuge crops or the illegal cultivation of Bollgard III seeds, must be considered. It is highly likely that this has often either led to untrue or missing responses.
A major limitation that led to biases throughout the data gathering process was the language barrier caused by my inability to speak either Telugu or Hindi. As a result, I entirely relied upon the translators and surveyors. Although we as a research team attempted to counteract this bias by briefing the translators and thoroughly training the surveyors in regard to content and methods relevant to this study, it is inevitable that information will get lost in the translation process.
Throughout the process of data acquisition, the research team tried to account for biases in gender and caste, which was not always successful due to varying reasons. The intention to avoid a bias in gender, for example, clashed with our overall survey objective to exclusively interview household heads in order to allow for representativity within the sample. We hence had to renounce to equally consider female Bt cotton farmers in order to give priority to the aspect of representativity. Female household heads were of course included in the sample, however. In addition to that, the aspect of caste representativity in the sample was often hard to execute for reasons of research ethics. For example, people of the former low/untouchable castes sometimes refused to talk to us, as they feared negative social consequences from people in their village environment if they were seen to be talking with white European

researchers. While we of course aimed to include Bt cotton-farming people from all castes in the sample in order to avoid biases in regard to caste, we also wanted to respect their wish not to talk to us. Other research ethical issues also arose at times if we did find someone of the former low/untouchable castes who was willing to talk to us. For example, again due to reasons of feared social consequences from other people in the village, one person insisted that we sat on chairs while they were sitting on the ground. Again, we respected this wish, even though it felt discriminatory against them and hence unethical, not only from a research but from a general ethical perspective. From these occurrences I deduct further biases among the interviewees in general due to my appearance as a white female European researcher. It is likely that this has caused further limitations, for example in regard to answering according to social desirability.

Another difficulty that I faced as a female researcher was related to my gender. While this helped me to gain the trust of female interviewees, I often felt not taken seriously or unheard in other, often male-dominated contexts, as I was often surrounded exclusively by men in public spaces during the field research. In this regard, I had to prevail when instructing male translators and surveyors.

5 The Return of Pink Bollworm in India’s Bt Cotton Fields: Livelihood Vulnerabilities of Farming Households in Karimnagar District

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Abstract

Since its introduction in India, Bt (*Bacillus thuringiensis*) cotton technology has been the object of controversial scholarly and non-academic debate. The recent return of pink bollworm (*Pectinophora gossypiella*) pests in several Indian states has provided cause for concern about wide-spread resistances in Lepidopteran pests towards the endotoxins produced in Indian Bt cotton plants as well as about severe setbacks in regard to cotton farmers’ livelihood security. This study is the first to provide empirical evidence on the socio-economic consequences of recent bollworm attacks in India based on an exploratory study conducted in Karimnagar district, Telangana, India. It analyses the changed vulnerabilities that smallholders currently face and identifies the reasons why some peasant farmers can only deal with the consequences of this technological failure to a limited extent.

Keywords: Bt cotton, genetic engineering, India, pink bollworm, rural livelihoods, Telangana

5.1 Introduction

Ever since its introduction, Bt (*Bacillus thuringiensis*) cotton technology in India has been accompanied by a controversial scholarly and non-academic debate (Choudhary and Gaur, 2010; Flachs, 2019a; Gutierrez et al., 2015; Kathage and Qaim, 2012; Kranthi, 2015a; Qaim, 2003; Scoones, 2008; Stone, 2007; Veettil et al., 2016). While agricultural economists stress the technology's importance in remedying a proclaimed agrarian crisis in the Indian cotton production through contributions to yield increases, improved revenue, and reductions in pesticide use (Choudhary and Gaur, 2010; Kathage and Qaim, 2012; Qaim, 2003; Sadashivappa and Qaim, 2009; Subramanian and Qaim, 2010; Veettil et al., 2016), other scholars question the technology's success and instead hold a multitude of agricultural factors responsible for improvements in the Indian cotton-producing sector in the early 2000s, such as the introduction of hybrids altogether, the spread of access to irrigation, and the increase in fertilizer application (Flachs, 2019a; Gutierrez et al., 2015; Kranthi, 2014, 2015b; Kranthi and Stone, 2020). Moreover, the technology's negative ecological side effects, i.e. outbreaks of secondary pests, and upcoming resistances in the target pest have been discussed (Flachs, 2019a; Gutierrez, 2018; Gutierrez and Ponsard, 2005; Kranthi, 2014, 2015b; Tabashnik and Carrière, 2019), its social implications, for example, its role in eroding farmers' knowledge, addressed (Flachs, 2019; Stone 2007), and its contribution to rural poverty reduction questioned (Glover, 2010).

Recent attacks of pink bollworm pests in Gujarat, Madhya Pradesh, Maharashtra, Karnataka, Andhra Pradesh and Telangana in the cotton season of 2017/2018 and earlier (Fand et al., 2019: 314; Mohan, 2017: 1988; Naik et al., 2018: 2544) have fueled the debate not only about potential resistances in Lepidopteran pests towards the endotoxins produced in Indian Bt cotton plants, but also about severe setbacks in regard to cotton farmers' livelihood security due to the technology failure. The recurring attacks of Lepidopteran pests throughout Indian states and the sudden decline in yield performance are now overshadowing initial hopes that were placed in Bt cotton technology in its early years of adoption.

In India alone, the lives of an estimated 60 million people are directly dependent on cotton production. Bt cotton technology plays a vital role in the agricultural sector and thus, the effects this industry has on people's livelihoods are of immense significance (Choudhary and Gaur, 2010: 3). This study fills the scientific void that had existed since the return of the pink bollworm in Indian Bt cotton fields was reported, in that it captures the socio-economic impacts of the recent return of the pest on cotton farming households. By following an exploratory livelihood approach, it examines the results of 42 problem-centred interviews conducted in Karimnagar district, Telangana. The study explores the changed vulnerabilities that smallholders currently face and examines the reasons why peasant farmers can only deal with the consequences of this technological failure to a limited extent.

5.2 Bt Cotton in India

Cotton production provides livelihoods and income for around 10 million rural households in India. Of these, 7.5 million smallholders have farm sizes of less than 10-15 acres and cotton holdings of 3-4 acres on average (Altenbuchner et al., 2018: 373; International Service for the Acquisition of Agri-Biotech Applications [ISAAA], 2017: 33; Kathage and Qaim, 2012: 1; Subramanian and Qaim, 2010: 296). The major cotton-producing states are grouped into three different zones of production, that is the northern (Punjab, Haryana and Rajasthan), central (Maharashtra, Madhya Pradesh, Gujarat, and Odisha), and southern zone (Andhra Pradesh, Telangana, Karnataka, and Tamil Nadu) (Arora and Bansal, 2012: 7; Choudhary and Gaur, 2010: 3; ISAAA, 2009: 3). While the northern zone is irrigated, accounting for 35% of land under cotton, both the central and the southern cotton cultivation zones are rain-fed, accounting for 65% of land under cotton (Choudhary and Gaur, 2015: 11; Gaurav and Mishra, 2012: 25; ISAAA, 2009: 3; Kaviraju et al., 2018: 1561). The cotton crop is grown in the season of *kharif*. It is sown in the monsoonal period starting in June and harvested in the time from October to January (ISAAA, 2017: 29; Kurmanath, 2018).

Since Lepidopteran insects are considered a major limiting factor in the production of cotton worldwide, genetically engineered (GE) seed technologies were developed to equip cotton plants with built-in protection against these damaging pests (Choudhary and Gaur, 2008: 15; Kathage and Qaim, 2012: 1; Naik et al., 2005: 1514; Subramanian and Qaim, 2008: 1). Bt crops produce endotoxins of the *Bacillus thuringiensis* bacterium, which have lethal effects on Lepidopteran insects (Khan et al., 2018). Following neoliberal economic reforms in the 1990s, the Indian agrarian sector was restructured in that state regulations were eased, seed production commercialized, and the farmer's role changed towards a more capitalist rationality. Alongside these changes, the Indian Genetic Engineering Approval Committee[25] (GEAC) authorized the release of the first generation of Bt cotton seeds for commercial cultivation in 2002 for the Indian market (Flachs, 2019a, 2019b; Kiresur and Ichangi, 2011: 68; Münster, 2012; Ramamurthy, 2000; Scoones, 2008). This first legalized GE crop in India was developed by the Indian seed company Maharashtra Hybrid Seeds Company (Mahyco) in a joint venture with the US-based company Monsanto called Mahyco Monsanto Biotech Limited (MMBL) (Qaim et al., 2006: 49; Sadashivappa and Qaim, 2009: 173). It remains the only legalized GE crop in India to date.

In the first years, MMBL produced three hybrids (MECH 12, MECH 162, MECH 184) with one induced gene (Cry1Ac) based on Monsanto's Bollgard-I technology (event MON-531) (ISAAA, 2009: 16; Kiresur and Ichangi, 2011: 68; Naik et al., 2005: 1514), which soon led to a sharp rise in the development of Bt hybrids and further events (Choudhary and Gaur, 2010: 13; Sadashivappa and Qaim, 2009: 173). One of these additional events, called MON15985, contained two induced genes (Cry1Ac and Cry2Ab) and became later known as Bollgard-II

[25] In 2010, the GEAC was renamed into Genetic Engineering Appraisal Committee (GEAC). At that time, the GEAC was deprived of the mandate to approve transgenic organisms and downgraded to a national appraisal committee without executive legal functions (Herring, 2015: 159).

(Choudhary and Gaur, 2015: 10; ISAAA, 2009: 12; Kukanur et al., 2018: 34). Today, Bollgard-I hybrids are almost completely replaced by seeds based on the Bollgard-II technology (Choudhary and Gaur, 2015: 5; see also Hallad et al., 2014: 224; ISAAA, 2016: 29).

The area under Bt cotton drastically increased throughout the country since the GE-technology was introduced (Choudhary and Gaur, 2015: 9; ISAAA, 2017: 28–29). Today, an estimated 93% of the area under cotton are cropped with GE plants (ISAAA, 2017: 28–29), underlining the vital role that Bt technology plays for India's cotton sector. It is grown in such quantities that India is today the world's fourth-biggest producer of GE crops, after the USA, Brazil, and Argentina (Kumar, 2015).

5.3 Bt Cotton Farming and Sustainable Livelihoods in India

5.3.1 Socio-Economic Effects of Bt Cotton Cultivation on Peasant Livelihoods

In regard to measuring and evaluating the socio-economic effects of Bt cotton cultivation on peasant livelihoods, the technology's effects on yields are controversial. Scholars with backgrounds in economics (e.g., Kathage and Qaim, 2012; Qaim, 2003; Sadashivappa and Qaim, 2009; Veettil et al., 2016) make claims that Bt technology increases effective yields. In these studies, the successes in yield increases of the early 2000s are almost entirely credited to the impact of Bt cotton (Kathage and Qaim, 2012; Plewis, 2014; Qaim, 2003; Qaim et al., 2006; Smale, 2016; Veettil et al., 2016). It is thus argued that Bt has strongly outperformed conventional cotton and yield advantages of up to 40% are ascribed to the impact of Bt technology (Kathage and Qaim, 2012: 2; Sadashivappa and Qaim, 2009: 172). However, other studies take several key trends in the Indian cotton production for overall yield increases into account (Flachs, 2019a; Glover, 2010; Gutierrez et al., 2015; Kranthi, 2014; Kranthi and Stone, 2020) and find lower contributions of the GE technology to increases in yields. Stone (2011: 395), for example, attributes only 18% of the suggested yield increase to the technology as such. In their recent long-term study, Kranthi and Stone (2020: 188) claim that 'yield increases are explained much better by other technological changes' and hence accredit yield increases of the early 2000s to a multitude of agricultural factors, such as the hybridization of cotton seeds, an improved access to irrigation facilities throughout Indian cotton-producing states, and most notably the rising use of fertilizer. Other scholars claim that 'the yield advantage of Bt over non-Bt is not statistically significant' (Gaurav and Mishra, 2012: 12), that it is unrelated to the technology, but rather to different cultivars and agronomic practices, and that yields have been stagnating or even falling during the last years (Stone and Flachs, 2015: 122).

Notwithstanding these differences, some scholars argue that higher effective yields have led to higher profits (Kathage and Qaim, 2012: 2; Maertens, 2017: 991; Plewis, 2014: 15; Sadashivappa and Qaim, 2009: 172; Smale, 2016: 1). Kathage and Qaim (2012: 1) claim a 50% gain in cotton profit among smallholders, which increased household living standards by 18% among Bt adopters and, additionally, increased household consumption (see also Yadav et al., 2018: 66). Hence, the authors conclude 'Bt cotton contributes to positive economic and social development' (Kathage and Qaim, 2012: 1) as most of the adopting peasant households are relatively poor. Sadashivappa and Qaim (2009: 172) furthermore claim that both these benefits (higher yields and an increment of profits) have been sustainable over time.

Also this line of argument, however, is not unchallenged: Several scholars describe the technology as increasing risks for farmers as it is not intrinsically yield-increasing, but instead, its performance depends heavily on local suitability, irrigation and/or rainfall conditions (Flachs, 2019a, 2019b; Gaurav and Mishra, 2012; Glover, 2010). This, in turn, means that 'any effects beyond protection against specific bollworm […] infestation' are not guaranteed (Gaurav and Mishra, 2012: 3). Moreover, while cotton is generally regarded as a risky crop in terms of yield variability, Gaurav and Mishra (2012: 3) argue that the yield fluctuations of Bt cotton are even higher than the variability of conventional cotton (see also Glover, 2010: 492; More et al., 2017: 161; Ramamurthy, 2011). These circumstances gain further significance when the higher production costs, such as higher seed costs, and recently even higher pesticide costs, associated with Bt cotton are considered (Arora and Bansal, 2012: 102; Gaurav and Mishra, 2012: 13; Glover, 2010; Kathage and Qaim, 2012: 2; Kranthi and Stone, 2020; Morse et al., 2007). Gaurav and Mishra (2012: 25) thus assert that the yield advantage promised by Bt seeds should 'be taken with a pinch of salt' as over the years, the rate of increase in net returns was lower than that of increase in inputs. From this finding, they deduce that the technology is not sustainable from a livelihood perspective and they conclude that there has been an 'increase in riskiness' (Gaurav and Mishra, 2012: 23–25) of cotton production since the introduction of Bt cotton technology.

Concerning pesticides, several short-term studies relying on data obtained before 2008 argue that usage and costs have decreased (Qaim, 2003: 2118; see also Subramanian and Qaim, 2010: 295; Tabashnik et al., 2005; Veettil et al., 2016). In field trials, Qaim (2003: 2118) found pesticide reductions of more than 60%. Kathage and Qaim remark that pesticide costs were significantly higher on conventional plots and claim that a 'widespread adoption of Bt has led to area-wide suppression of bollworm populations' (2012: 2), consequently causing conventional farmers to substantially reduce their pesticide applications. In addition to that, Veettil et al. found that there have been reductions in pesticide usage 'across all toxicity classes over time for both Bt and non-Bt cotton' (2016: 118). Later long-term studies, on the contrary, purport that a decrease in pesticide usage can only be assigned to the initial phase of Bt cotton introduction and that by 2010, when Bt technology diffusion was ubiquitous in India, 'total insecticide applications had largely returned to their pre-GM levels' (Flachs, 2017: 2; see also Flachs, 2019a; Kranthi, 2015b; Kranthi and Stone, 2020). Kranthi and Stone (2020: 188) even claim that farmers are 'now spend[ing] more on insecticides than before they adopted *Bt* seed'.

A further factor pushing pesticide use has been the ecological changes in the incidence of sucking pests. Formerly, these were less problematic and regarded as secondary pests (Kathage and Qaim, 2012). However, Bt technology caused a decline in primary pests leaving an ecological niche that sucking pests have now filled. This increase in sucking pests - which are not susceptible to Bt technology - requires farmers to increase their spending on pesticides (Flachs, 2017, 2019a; Gaurav and Mishra, 2012; Kranthi 2014, 2015b; Kranthi and Stone, 2020; Stone and Flachs, 2015: 123).

5.3.2 The Return of Pink Bollworm in India's Bt Cotton Fields

Recently, a critical turning point has occurred in the production of Bt cotton, as the main target pest, the pink bollworm, has returned to several Indian cotton-producing states. The infestation has spread throughout the central and southern zone of cotton production since the *kharif* season of 2015, affecting fields in Gujarat, Madhya Pradesh, Maharashtra, Karnataka, Andhra Pradesh and Telangana with anticipated yield losses of up to 30% (Fand et al., 2019: 313; Mohan, 2017; Naik et al., 2018). This incident has caused great concern amongst Bt cotton farmers and other stakeholders in the cotton industry and has reignited the debate regarding the technology's longevity. While Bt cotton technology promised built-in protection against pink bollworm and other Lepidopteran pests, it is now claimed to have 'lost the battle' (Fand et al., 2019: 314). In this context, several potential causes for the pest's re-occurrence are debated, of which we address only those that are directly related to farmers' livelihoods systems, namely the circulation of illicit and spurious seeds, and the requirement of growing refuge crops around Bt plants.

A first potential cause for the pest's recurrence is seen in the prevalence of informal seed markets. Since Bt cotton seeds are associated with higher costs compared to conventional cotton seeds (Gaurav and Mishra, 2012; Kathage and Qaim, 2012) and due to a 'stronger formal intellectual property (IP) status' (Herring and Kandlikar, 2009: 57), there are strong incentives for informal markets to emerge. The traded illicit seeds do have detrimental effects on the fight against bollworm, since low-quality seeds often mean low pest protection. This latter aspect is due to varying levels of Bt toxins to be expressed in transgenic cotton plants. In the case of stealth and counterfeit seeds, it cannot be guaranteed 'that the toxin protein be expressed in adequate quantities' (Bakhsh et al., 2012: 115; see also Khan et al., 2018; Singh et al., 2016) for the technology to maintain its functionality over the entire season. Moreover, the issue of illicit seeds affects market transparency and farmers' capacities to make a choice based on reliable information (Flachs, 2019a; Stone, 2007). As farmers tend to use new seeds each season, because they strive for the most popular brand and type, they 'largely disregard […] what they know about the previous years' seeds' (Flachs, 2019a: 84; see also Stone, 2007; Stone et al., 2014). Hence, farmers rarely re-plant seeds, and are thus limited in their environmental learning within an increasingly untransparent seed market (Flachs, 2019a; Stone, 2007; Stone et al., 2014).

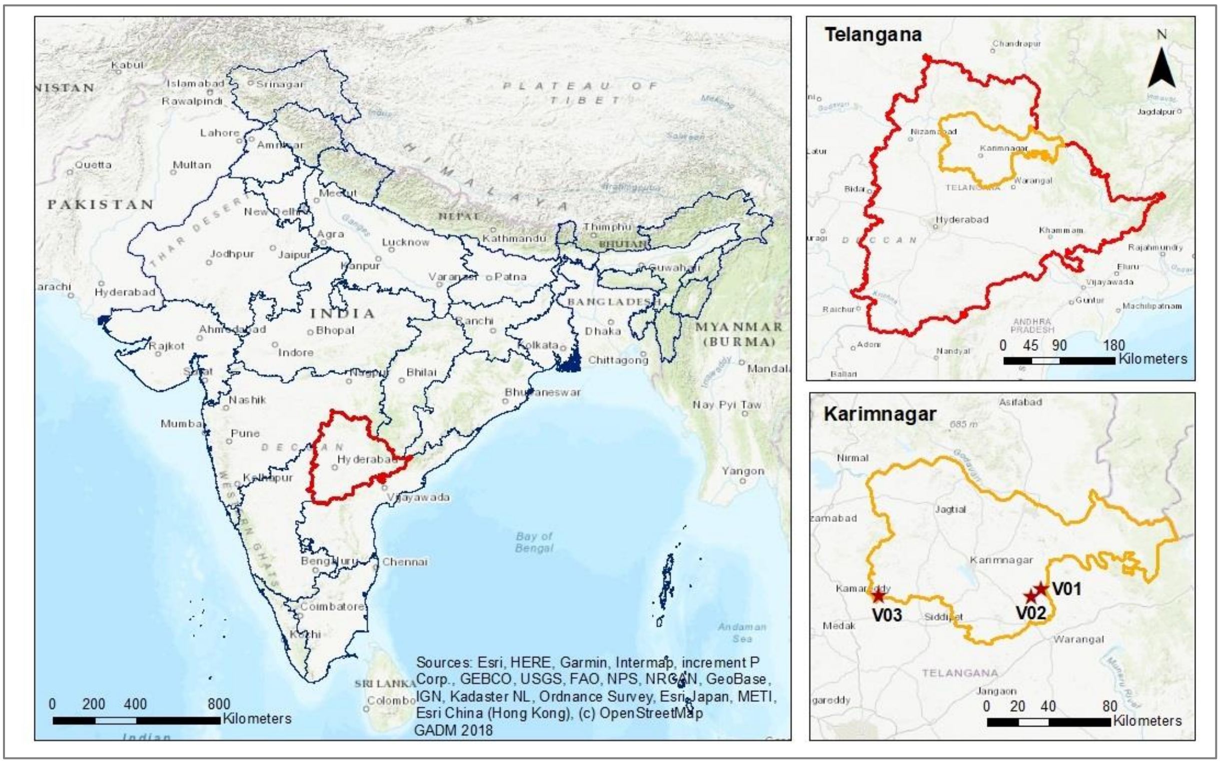
A second potential cause for the pest's recurrence is seen in the non-compliance of farmers with refuge requirements (ISAAA, 2017, 2018; Mohan, 2017, 2018). For planting GE cotton, refugia consisting of non-GE cotton crops are required to surround each field in the ratio of at least 95:5 (GE:non-GE crops) in order to lower the evolutionary pressure of the pest to adapt to the endotoxins produced by the Bt plants (Carrière et al., 2005: 327; Flachs, 2017: 2; Jayan, 2018; Liu et al., 1999; Zhang et al., 2011: 1). While the ISAAA (2017: 29) blames mismanagement of the technology for the 'erosion of resistance to pink bollworm', it argues that the technology's efficacy could have been prolonged if farmers had followed instructions. Others instead hold the technology itself responsible: as Glover (2010: 502) claims, the technology needs to be evaluated in context as it is not just 'in the seed', but has to 'function in particular socio-technical and institutional settings'.

Given the recently reignited controversy about the return of pink bollworm in India's Bt cotton fields, in this study we raise the following two questions: (a) How did the adoption of the Bt technology generally affect the livelihoods of farming households in Karimnagar district in the recent past? (b) What immediate livelihood vulnerabilities have the erosion of host resistance, and with it the return of pink bollworm pests, caused among farming households in Karimnagar district and how do they cope with this new situation?

5.4 Methodology

In order to answer these questions, we designed this study after the Sustainable Livelihood approach (SLA) (Carney, 2003; Scoones, 1998). According to Chambers and Conway, 'a livelihood comprises the capabilities, assets (stores, resources, claims, and access) and activities required for a means of living: a livelihood is sustainable which can cope with and recover from stress and shocks, maintain or enhance its capabilities and assets, and provide sustainable livelihood opportunities for the next generation; and which contributes to net benefits to other livelihoods at the local and global levels and in the short and long term' (1992: 6).

The SLA puts the livelihood system of households centre stage and serves to study the underlying capital (assets), members' strategies of accumulation (activities), influencing social, economic and ecological factors (capabilities), and the respective outcomes of livelihood systems (sustainability) in particular contexts (Carney, 2003; Conway et al., 2002; Krantz, 2001; Kollmair and Gamper, 2002; Moser, 2008). The approach not only refers to households' income, but aims at examining how this income is generated, how the livelihood system is maintained, and how a household's entitlements are enhanced (Chambers and Conway, 1992). Livelihood studies thus aim at revealing a household's means and strategies to deal with certain long-term trends, seasonalities and sudden shocks and intend to identify possible adjustments to help reduce their vulnerability. From a livelihood perspective, households try to manage their livelihood security over both the short and over the longer term and as such risk and resilience are central concepts in livelihood analysis (Chambers and Conway, 1992).



[Publication 1] Figure 1: Empirical Fieldwork in Karimnagar District in Telangana, India
Source: The authors.

In this study, we followed an exploratory and therefore non-representative, qualitative research design with 42 problem-centred interviews, which we conducted in August and September 2018—and thus during the 2018/2019 cotton season—in three selected locales in Karimnagar district in the Indian state of Telangana (see Figure 1). The exploratory approach was chosen as the recurrence of the target pest urged us to change our focus from general agricultural decision-making processes in cotton-producing households to the particular capacities of cotton farmers to cope with the returned pink bollworm.

The Karimnagar district is located north of Hyderabad in the state of Telangana and belongs to the southern zone of cotton production. We chose this district as study region, because it is one of the state's major cotton-producing districts and neighbouring districts have already been the object of earlier Bt cotton-related studies (Kaviraju et al., 2018; Kukanur et al., 2018; Stone, 2011; Stone and Flachs, 2015). These earlier studies provided a basis for comparison and were hence helpful in identifying recent changes of the impacts of Bt cotton technology on farmers' livelihoods.

Our access to the field was facilitated by colleagues from the University of Hyderabad and the Loyola academy in Secunderabad. We chose the sample villages according to the criterion of most area under cotton and based on our colleagues' local knowledge of the area. By accompanying some of their students, who were completing their practical training, we were able to establish the first access to the field easily (village 1; see Table 1). The local cotton miller informed us about a neighbouring village involved in cotton production and this became our second study village (village 2; see Table 1). The third village (village 3; see Table 1) was again chosen because a large share of its agricultural area was under cotton. Due to its long geographical distance to the first two sample villages, it served as a counterpoise. Here, we established contacts to the peasant community through an inputs shop owner in the nearby district town. Within the three villages, we found interview partners by means of random walks, on which we found volunteering cotton farmers as interview partners. This sampling process allowed for a more diversified group of interviewees in terms of farming characteristics than snowball sampling alone.

Two interpreters, fluent in English, Hindi, and Telugu, assisted us in communicating with the local village councils (*gram panchayat*). With their help, we were able to interview a total sum of 35 peasants (male and female), two owners of shops selling inputs (for fertilizer, pesticides, seeds, and so forth), one owner of a mid-size cotton mill, one coordinator of a local branch of the governmental extension service (*Krishi Vigyan Kendra*, KVK), one commission agent active in cotton trade, one representative of an Indian seed company, and one head of a village council (*sarpanch*) (see Table 1).

[Publication 1] Table 1: List of interviews

No*	Name	Expertise	Landholding size	Date
V01-I01	**Mari Jagan** (m)	Peasant	11 acres owned: paddy, cotton, chili	10.09.18
V01-I02	**Mahendra** (m)	Peasant	7.5 acres owned: paddy, cotton	11.09.18
V01-I03	**Mamatha** (f)	Peasant	7.5 acres owned: paddy, cotton	11.09.18
V01-I04	**Karmagala Lakshmi** (m)	Peasant	11 acres owned: paddy, cotton, turmeric	11.09.18
V01-I05	**Parameshwari** (f)	Peasant	11 acres owned: paddy, cotton, turmeric	11.09.18

V01-I06	**Mari Jagan** (m)	Peasant	11 acres owned: paddy, cotton, chili	11.09.18
V01-I07	**Lavanya** (f)	Peasant	11 acres owned: cotton, maize, turmeric	11.09.18
T01-I01	**Satish** (m)	KVK representative		12.09.18
T01-I02	**Mukka** (m)	Cotton mill owner		12.09.18
V01-I08	**J. Mala** (m)	Peasant	No owned land, hired laborers	12.09.18
V01-I09	**Gujala** (f)	Peasant	No owned land, hired laborers	12.09.18
V01-I10	**Pulajillala** (f)	Peasant	No owned land, hired laborers	12.09.18
T01-I03	**Krishnamurthy Ch.** (m)	Inputs shop owner		13.09.18
V01-I11	**Jelander** (m)	Peasant	1 acre owned: cotton, paddy	13.09.18
V01-I12	**Rama** (f)	Peasant	50 guntas owned: cotton, paddy	13.09.18
T01-I04	**Tirupaddy** (m)	Commission agent		14.09.18
V02-I01	**P. Ravindar** (m)	Peasant	6.5 acres owned: cotton, paddy, on lease	17.09.18
V02-I02	**Ram** (m)	Peasant	3 acres owned: cotton, paddy	18.09.18
V02-I03	**Lakshmi Srinivas** (m)	Sarpanch		18.09.18
V02-I04	**Mugula** (m)	Peasant	8 acres: 4 acres owned, 4 acres leased: paddy, cotton	18.09.18
V02-I05	**Thirupati** (m)	Peasant	6 acres owned: cotton, paddy	18.09.18
V02-I06	**Damodar** (m)	Peasant	1.5 acres owned: cotton	18.09.18
V02-I07	**Mahindar** (m)	Peasant	4 acres owned: turmeric, chili, paddy, cotton	18.09.18
V02-I08	**Tirupati G.** (m)	Peasant	5 acres: 2 acres owned, 3 acres leased: cotton, paddy	18.09.18
V02-I09	**Parusharam** (m)	Model farmer	10 acres: 5 acres owned, 5 acres leased: cotton, paddy	19.09.18
V02-I10	**Md. Rahimodhin** (m)	Peasant	4.5 acres: cotton, paddy	19.09.18
V02-I11	**Kasturi** (m)	Peasant	8 acres: 6 acres owned, 2 acres leased: cotton, paddy	19.09.18
V02-I12	**N. Venkateshwarlu** (m)	Peasant	24 acres owned: cotton, paddy, on lease	19.09.18
V02-I13	**Mohamad** (m), **Jarina** (f)	Peasants	2 acres owned: cotton, paddy	19.09.18
V02-I14	**Sanjeev** (m)	Peasant	1 acre owned: cotton	19.09.18
T02-I01	**Vijay Reddy** (m)	Inputs shop owner		23.09.18
V03-I01	**N. Raju** (m)	Peasant	15 acres: 5 acres owned, 10 acres leased: cotton, maize	24.09.18
V03-I02	**Kalakonda Narasimha** (m)	Peasant	20 acres owned: cotton, maize, paddy	24.09.18
V03-I03	**C.H. Narayana** (m)	Peasant	5 acres: 4 acres owned, 1 acre leased: cotton	24.09.18
V03-I04	**Ramana** (m)	Peasant		24.09.18
V03-I05	**Karra Srinivas** (m)	Peasant	16 acres: 1 acre owned, 15 acres leased: cotton, maize, paddy	24.09.18
V03-I06	**Chiluka** (m)	Peasant	8 acres: 6 acres owned, 2 acres leased: cotton, paddy	24.09.18

V03-I07	**Naran** (m)	Peasant	10.5 acres: 1.5 acres owned, 9 acres leased: cotton, maize	24.09.18
V03-I08	**Mandhala Linga** (m)	Peasant	18 acres owned: cotton, paddy	24.09.18
V03-I09	**Raj** (m)	Peasant	9 acres: 6 acres owned, 3 acres leased: cotton, paddy	25.09.18
V03-I10	**Janardan** (m)	Peasant	6 acres owned: cotton, paddy	25.09.18
T03-I01	**Tharun** (m)	Seed production enterprise		26.09.18

* "V"stands for village; "T" stands for town; "I" stands for interview partner

The semi-structured interview guide was conceptualized in accordance with the livelihood analysis. Accordingly, in the interviews, emphasis was placed on the assets of the farmer households, that is natural, physical, human, financial, and social capital (Ellis, 2000; Moser, 2008; Scoones, 1998). These assets are modified by the social, economic and ecological factors in which a household is embedded (Ellis, 2000; Moser, 2008; Scoones, 1998). The vulnerability context of livelihoods systems includes trends, seasonalities, and shocks (Ellis, 2000; Scoones, 1998). Livelihood outcomes are mediated by differences in livelihood activities, household assets, the vulnerability context and wider social, economic and ecological factors (Ellis, 2000).

In the following part, we focus on the changes linked to the adoption of Bt technology and on the shock caused by the recurred infestation of pink bollworm pests in the season of 2017/2018 from a livelihood perspective.

5.5 Results

5.5.1 Changes Linked to the Adoption of Bt Seeds

Most of the farmers we interviewed owned at least some of their cultivated land, while several of them leased large parts. The farm sizes of our respondents varied from one acre to 24 acres and can therefore all be considered as small-scale. The amount of leased land varied between one and 15 acres (see Table 1).

According to our interviewees, all seeds they used for cotton cultivation were Bt II hybrids but varied in brand and type. The most frequently mentioned brands were Rasi (*659, RCH 2*), Mahyco (*Dr Brent*), Bayer (*Surpass First Class*), Nuziveedu (*Bhakti*), and Veda (*Sadanand*) (V01-I02; V01-I04; V02-I01; V02-I04; V02-I11; V03-I02; V03-I09; T02-I01). All farmers claimed to be using more than one variety for reasons of diversification and deficient yield performance (V01-I02; V01-I04; V02-I01; V02-I04; V02-I11; V03-I02; V03-I09; T02-I01).

Illicit seeds were mentioned to be an issue by several interviewees and here, counterfeit seeds, causing negative effects on farmers' yields, were described as more prevalent and problematic than stealth seeds (V01-I04; V02-I08; V02-I12; V02-I13; V02-I14; V03-I01; V03-I04; V03-I10). According to the interviewed farmers, these 'faulty' or 'spurious' seeds started entering the market only with the advent of transgenic seeds (V02-I12; V03-I04) and were not available before. For the farmers, it is impossible to identify them and tell them apart from original seeds as they come in 'fancy packaging and use more or less the same names' (V03-I04; see also V02-I08; V03-I01). In the view of our interviewees, it is the government's responsibility to prevent the entry of faulty seeds into the market (V02-I12; V02-I13; V02-I14; V03-I01; V03-I04).

All interviewed farmers described the trend in yields as a curve which had increased significantly in the first years after Bt cotton adoption, but had recently declined sharply. Our interviewees described the high yields of the early years after adopting the Bt technology as a drastic 'boom' (V02-I07; V02-I08). This initial upturn had improved the economic situation of the vast majority of our respondents, as they had been able to make significant investments. Interviewed farmers claimed that they had been able to construct or renovate their houses or to buy land and machines (such as rickshaws, tractors, and harvesters), which had enabled them to diversify their income sources (V02-I012; V03-I10). Moreover, several of them had used their initial surpluses for covering expenses related to their children's education (V02-I08; V02-I12; V03-I8; V03-I10).

Apart from these positive evaluations, the interviewees also mentioned some drawbacks: Several farmers reported that the yields of non-Bt cotton had been 'not huge, [but] some yield was always ensured' (V02-I06; V02-I12). Altogether, they described them as more constant, whereas those of Bt cotton were termed as more oscillating (V02-I12). One interviewee (V02-I12) claimed that with Bt cotton, 'the yields can be good during one year and not fruitful during the next year' and concluded that Bt cotton was an 'erratic crop'. Similarly, another peasant described Bt cotton as 'very risky' and claimed that cotton farmers, today, will either get a high yield or 'totally lose it' (V02-I06). With non-Bt cotton, in contrast, they had been able to get reliable yields as long as they had worked properly and put enough efforts into it (V02-I12).

Similar to the trend observed in yields, our interviewees described that the quantities of pesticides required had decreased noticeably after the adoption of Bt cotton, but had increased again only a few years later (V02-I07; V02-I08; V02-I12). In terms of pesticides applied, they claimed, quantities required for cultivating Bt cotton are today almost at the same level as the amount needed before for non-Bt cotton. The reason for this, according to the peasants, was a general increase in pest infestation (V02-I07; V02-I08; V02-I12).

According to the interviewed farmers, the most drastic change with the adoption of Bt technology is the alteration of the crop cycle, since crop growth is significantly shorter for Bt cotton than for non-Bt cotton hybrids. While sowing usually takes place in June for Bt as well as non-Bt cotton seeds, the period of harvesting non-Bt cotton had stretched out until January, while harvesting Bt cotton can now be accomplished by November. This shortened growth phase allows farmers to grow a second crop on the same plot, which is mostly maize. The possibility of growing a second crop each year was stated by farmers as being the major benefit of Bt cotton, resulting in additional household income and increased wellbeing (V02-I13; V02-I11; V03-I09).

This privilege is, however, limited to those farmers who are able to provide sufficient amounts of water to the crop (V2-I10; V2-I14). If water supply is insufficient, for example, due to a lack of irrigation systems, the second crop can either not be planted at all or is exposed to new risks. One interviewee described that, after having lost his first crop (Bt cotton) to pink bollworm infestation in the season of 2017/2018, he also lost his second crop (maize) due to a lack of water supply (V2-I13). Hence, instead of balancing his losses, his second crop indebted him even further.

Moreover, some of our interviewees complained that the Bt crop created further negative effects in cropping patterns. The earlier flowering of Bt cotton hybrids exposes them to damage from the rains common during the *kharif* season. One farmer explained that 'the flowering of non-Bt plants started after the rainy season whereas the flowering stage of Bt cotton […] starts during the rainy season' (V02-I07). This is problematic, since 'during the cotton boll's birthing stage, water will drain [now] into the boll and cause it to just fall down' (V02-I12).

In regard to growing so-called refuge or trap crops, all interviewed farmers reported that they did not comply with the instructions given by seed companies for economic reasons (V02-I06; V02-I07; V02-I08; V02-I12). They stated that the non-Bt seeds were of minor quality and the resultant cotton not sellable to the market. In the end, the farmers would experience financial disadvantages, if they planted the non-Bt seeds—a fact that they avoided by planting their entire field with Bt seeds only (V02-I06; V02-I07; V02-I08; V02-I12).

5.5.2 Impacts of the Pink Bollworm Pest Infestation in 2017/2018

The infestation of the pink bollworm pest in Telangana in the season of 2017/2018 has severely impacted cotton farmers' yields with negative effects on peasant livelihoods. The target pest is reported to have returned to central and southern Indian cotton-producing states since the kharif season of 2015 (Fand et al., 2019; Mohan, 2017). As our survey, conducted in August and September 2018, captures the ramifications of the 2017/2018 infestation, this is what our analysis focuses on. Although we have no data for subsequent seasons, we can infer that this problem had ramifications for the following seasons in terms of lower and unpredictable cotton yields. All interviewed farmers confirmed these attacks and claimed to have suffered severe financial losses. One farmer's response illustrates the risk associated with this recent collapse in Bt cotton production: He described how he started building his house with the surplus accumulated during the initial years of his adoption of the technology, but then - after the pink bollworm pest had returned - he could not manage to earn enough money to finish the construction (V02-I07). Another respondent, a 70-year-old farmer, claimed that he 'cannot remember a similar shock like this' (V02-I13).

Despite the fact that all interviewed peasants grew Bollgard-II with alleged built-in pest resistance, pink bollworm was claimed to have returned as 'the major problem' of cotton production in all three villages studied (V01-I01; V02-I02; V02-I11; V03-I01; V03-I09). Most of our respondents said that they were taken by surprise by these recurring pest attacks. One farmer explained how a KVK employee informed him of the infestation.

> *I could not believe it initially but […] the employee asked me to open one cotton boll and check it. […] So later this day I came to my field and I was very hesitant to open one of the cotton bolls in the beginning, because I thought that if I opened it, it would be wasted. But reluctantly I did and I saw that it was completely infested by pink bollworm. Later I was so desperate that I opened nearly 50 cotton bolls just to make sure that they were not affected, but unfortunately the whole field was infected by pink bollworm* (V02-I01).

While secondary pests were mentioned to be problematic in Telangana (V01-I03), most of our interviewees focused on the issue of the recurrence of pink bollworm infestations. This recurrence let some of the peasants assume that pink bollworm had developed a resistance against the Bollgard-II technology. One peasant, for example, argued that 'at first, Bt I (Bollgard-I) lost its resistance to the pest and Bt II (Bollgard-II) is now following' (V02-I14).

In order to cope with this unexpected situation, the vast majority of our respondents had to take loans to buffer this economic shock (V01-I10; V02-I06; V02-I07; V02-I13; V02-I14; V03-I05; V03-I06). For these loans, they preferred the formal bank system. Yet, access was restricted to either land-owning farmers, or to those farmers who could offer another kind of deposit, such as gold or jewellery (V01-I10; V02-I06; V02-I08; V02-I13). Interviewees who did not own enough land had to take loans from informal sources such as money lenders or commission agents (V02-I13; V02-I14; V03-I05; V03-I06). Since these informal sources demanded higher interest rates than formal banks, some farmers were not able to pay off their loans, so that many were still indebted at the time we conducted the interviews (for example V02-I14). One farmer, ironically one who had once won an award for his distinguished agricultural expertise and performance, said that he had needed to borrow money from several moneylenders one after another. In this way, he managed to pay back the interest to one of them, allowing him to delay full repayment (V02-I14). As last resort to cope with the incurred losses, several interviewed farmers explained that they had been forced to sell some of their land (V02-I14; V03-I05; V03-I07; V03-I10).

5.6 Discussion

As our findings show, the implementation of Bt cotton technology has had varying impacts on cotton farmers' livelihoods. While initial uplifts, such as improvements in yield performance, were reported by our interviewees, our findings revealed new vulnerabilities for cotton farmers' livelihoods related to the implementation of Bt cotton and the recent return of pink bollworm to Bt cotton fields.

Our findings confirm the initial socio-economic improvements among Indian cotton-producing households in the early 2000s. Initial increases in yields were experienced by our interviewees as an economic boom (V02-I07; V02-I08), which benefitted farming households with varying landholding sizes and backgrounds alike, and which enabled many of them to make significant investments (V02-I08; V02-I12; V03-I07; V03-I10). These were mostly of a long-term character (building or renovating houses, purchase of machines, investments in children's education) and thus enhanced rural wellbeing. Moreover, they allowed some farmers to pursue diversified strategies of income generation (lending machines, rickshaw services) (V02-I012; V03-I10). As a result, the initial increase of farmers' income and the enhancement of rural households' wellbeing, as reported by some studies (Kathage and Qaim, 2012: 3; Plewis, 2014: 15; Sadashivappa and Qaim, 2009: 172; Yadav et al., 2018: 66), can be substantiated. Yet, while these improvements are attributed by some academics to the Bt technology (Kathage and Qaim, 2012; Qaim, 2003; Smale, 2016; Veettil et al., 2016), our findings cannot provide evidence for or against an isolated effect of the technology.

In contrast, our findings provide clear evidence of a return of pink bollworm in Telangana and confirm that this has caused severe impacts on farmers' livelihoods. As all interviewed farmers reported to have suffered from pink bollworm infestation in the cotton season of 2017/2018, we suggest that Bollgard-II seeds have lost their effectiveness in this particular area. As the Bt technology is claimed to provide protection against this pest, its long-term performance, and with that its impacts on cotton farmers' livelihoods, require a critical re-evaluation.

All farmers reported a severe collapse in yields and therefore an increase in the riskiness of Bt cotton cultivation. This collapse in yields in 2017/2018 forced farmers to pursue strongly responsive livelihood strategies. The most common strategy to buffer the economic shock caused by pink bollworm pests was to take up loans (V01-I10; V02-I06; V02-I07; V02-I13; V02-I14; V03-I05; V03-I06). In this respect, landowning farmers, especially those with larger landholding sizes, were able to cope with the situation more easily, as they benefitted from access to the formal bank system (V01-I06; V02-I02; V02-I04) or had enough savings to cover their losses (V01-I04; V02-I12; V03-I05; V03-I08). Farmers with smaller landholding sizes, in contrast, were facing clear disadvantages, as they were excluded from the formal bank system and thus had to rely on moneylenders (V02-I13; V02-I14; V03-I05; V03-I06). These informal sources generally demand higher interest rates and can lead asset-weak farmers into debt traps: already vulnerable households had to deal with an additional financial risk from the shock of the unexpected pest infestations experienced in the season of 2017/2018. Several interviewed farmers explained that they had to sell some of their land as last resort to cope with the incurred losses and to pay off their debt (V02-I14; V03-I05; V03-I07; V03-I10). The selling of land corrodes the foundations of their agriculture-based livelihoods and needs to be seen by policymakers as clear alarm signal.

According to our interviewees, the collapse in yields is the peak of an increasing unreliability of the cotton crop. The yield performance was described as more 'erratic' or 'oscillating' compared to non-Bt cotton (V02-I06; V02-I12) and is thus creating new vulnerabilities for cotton farmers' livelihoods. This confirms Gaurav and Mishra's (2012) findings of higher production risks associated with Bt cotton cultivation (see also Glover, 2010: 492; More et al., 2017: 161). The increased unreliability is met by farmers by diversifying their production. While all interviewed farmers diversified their cotton production in terms of the brands and varieties of seeds sown, some even diversified their agricultural production altogether (V01-I02; V02-I12; V02-I14; V03-I05; V03-I06; V03-I10). Some farmers claimed to have already shifted part of their production towards other crops such as turmeric, chilli, maize, or paddy (V03-I04; V03-I05) or were planning to do so if the cotton yield failed again the following season (V02-I05; T02-I01; V03-I06; V03-I08). In regard to the diversification of agricultural production, economically underequipped farmers face severe disadvantages. Firstly, due to smaller landholding sizes, they are unable to dedicate much land to an experimental diversification. As a result, the safety net created through a diversified cultivation is disproportionally smaller than that of farming households with larger landholdings. Secondly, the strategy of crop diversification is limited to those farmers who have sufficient water supplies at their disposal, since most other locally cultivated crops are more water intensive (V01-I02; V01-I11; V02-I12; V02-I14; T02-I01; V03-I10). Access to sufficient water resources is thus a crucial risk-diminishing factor, especially in the mostly rain-fed areas of Telangana. In sum, the risk of yield setbacks due to returned pest infestations is more likely to affect already vulnerable livelihoods more severely.

All interviewed farmers varied their seeds in brand and type and cultivated more than one variety per season. They did so to distribute the risk regarding the performance of each seed type (V01-I02; V01-I04; V02-I01; V02-I04; V02-I11; V03-I02; V03-I09; T02-I01). This diversification of Bt II-hybrids is seen as preventive strategy in response to 'faulty' or 'spurious' seeds in the market, as farmers cannot tell counterfeit and original seeds apart (V01-I04; V02-I08; V02-I12; V02-I13; V02-I14; V03-I01; V03-I04; V03-I10). However, a high degree of switching between seed brands, types or varieties can undermine the process of building up farmer's knowledge about what works best in their environment (Flachs, 2019a, 2019b; see also Stone et al., 2014). Thus, if the Indian government has an interest in building up farmer's knowledge and ability to make discerning seed choices, it needs to get rid of the country's highly opaque and uncontrolled seed market, which evolved with neoliberal reforms in India's agricultural sector preceding GE technology (Flachs, 2019a; Stone, 2007; Stone et al., 2014). In regard to the altered growth cycle of Bt cotton it needs to be seen that farmers with access to irrigation systems benefitted from the shortened growth period, as they were able to plant a second season of maize in their cotton fields (V02-I07; V02-I11; V02-I12; V02-I13; V03-I09). This group clearly profited from adopting the GE crops. At the same time, however, farmers without sufficient water were either not able to grow a second crop or were exposed to new risks by relying on unruly weather conditions (V2-I10; V2-I13; V2-I14). The benefits associated with the shortened growth duration of Bt cotton are thus limited only to those farmers who are economically better off - even though economically weaker farmers also adopted double cropping. Given India's non-transparent seed markets outlined above, small-scale farmers are more than ever orienting themselves towards the successes of larger landowners and emulate their capitalist rationalities, even if these are associated with an increased personal risk exposure (Keck, 2019: 110).

The last point we want to make is concerned with the required refuge crops for growing Bt cotton. All interviewed farmers reported that they did not comply with the instructions given by the seed companies (V02-I06; V02-I07; V02-I08; V02-I12) despite the fact that this strategy threatens the longevity of the technology and thus stands in direct opposition to farmers' long-term economic goals. And yet, we argue, blaming farmers for mismanaging the technology is at best short-sighted. From their perspective, they follow a capitalist logic, seeking to maximize short-term profits, while refugia imply lower yields and income. It is therefore up to political decision-makers, administrations and the seed companies themselves to take responsibility and provide incentives for farmers to grow refuge crops and help prolong the technology's functionality.

5.7 Conclusion

This study shows that the impacts of the Bt cotton technology on farmers' livelihoods in Karimnagar are diverse and have altered over time. The initial years of Bt cotton adoption were characterized by perceptible increases in yields, noticeable reductions in pesticide use, and improved economic wellbeing. In the season of 2017/2018, however, all interviewed farmers stated that they suffered great yield losses due to pink bollworm infestation - a Lepidopteran pest that Bt technology is claimed to provide protection against. This pest infestation had tremendous negative effects on farmers' livelihoods and the resultant new vulnerabilities disproportionately affected asset-weak households. The failure of Bt technology has therefore put predominantly those farmers with marginal assets at great risk.

Given the return of pink bollworm in Indian cotton fields, we see cause for concern that the built-in pest control in the second generation Bt cotton technology (Bollgard-II) is no longer functional. This represents a threat to the livelihoods of cotton farmers in India. Against this background, we call for the establishment of an independent body to conduct area-wide testing to determine the level and duration of transgene expression in commercialized Bt cotton plants in India. We suggest such a testing is urgently needed to combat the sale of counterfeit seeds, which might be of low quality or do not show any Bt-related traits at all. We furthermore call for an inquiry to examine the levels of resistance of Lepidopteran moths to the endotoxins produced by the GE cotton plants in India. Such an inquiry will provide a more clear-cut picture about the risks for farmers and the longevity of this technology. Last but not least, a representative survey is needed to determine the geographical extent of the return of pink bollworm and the socio-economic costs that it is imposing on farming households in India. Equipped with these numbers, farmers' groups will have the evidence with which to formulate claims for compensation from large seed corporations and to address the government to provide them with support.

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6 Bt cotton, pink bollworm, and the political economy of sociobiological obsolescence: insights from Telangana, India

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Abstract

After genetically engineered Bt cotton lost its effectiveness in central and southern Indian states, pink bollworm infestations have recently returned to farmers' fields and have substantially shifted their vulnerability context. We conceive Bt cotton as a neoliberal technology that is built to protect farmers only temporarily from Lepidopteran pests while ultimately driving the further concentration of capital. Based on data from a representative survey of the three major cotton-producing districts of the state of Telangana (n = 457), we find that pink bollworm pest infestations are a shock to farmers that lead to severe losses in yield and income. Using the vulnerability concept as a framework, we embed our findings in a political-economic context by drawing on Harvey's notion of accumulation by dispossession. We argue that Bt cotton includes an inherent sociobiological obsolescence that results in a systematic dispossession of resource-poor households while providing appropriation opportunities for other actors. Finally, reproduced hegemonic structures facilitate the accumulation of capital through a redistribution of assets from the bottom to the top of the agricultural sector. Claims that considered Bt cotton as a pro-poor technology were thus flawed from the outset.

Keywords: Biotechnology, Capitalism, Food regime analysis, Livelihood, Resilience, Socionatures

6.1 Introduction

Since its commercialization in India in 2002, genetically engineered Bt (*Bacillus thuringiensis*) cotton has been subject to controversial scientific and public debate (Qaim 2003; Stone 2011; Kathage and Qaim 2012; Choudhary and Gaur 2015; Gutierrez et al. 2015; Kranthi 2015; Veettil et al. 2016; Flachs 2019a). This controversy around Bt technology has been reignited by the recent reoccurrence of pink bollworm (PBW) pest infestations in several central and southern Indian cotton-producing states, such as Gujarat, Madhya Pradesh, Maharashtra, Karnataka, Andhra Pradesh, and Telangana (Mohan 2017; Naik et al. 2018; Fand et al. 2019). As the bollworm complex[26] accounts for major limitations in the global production of cotton, controlling the threat associated with these borer insects is considered a primary objective in cotton-producing sectors worldwide (Naik et al. 2005; Choudary and Gaur 2015; Kaviraju et al. 2018; Fand et al. 2019). This is especially true for India, which is the leading producer of cotton worldwide and contributes a quarter of the global production, which is cultivated by 7.7 million smallholders (Choudhary and Gaur 2015; Shahbandeh 2019).

In this context, Bt cotton, with its integrated pest protection ability, has been heralded as a silver bullet by proponents of Bt technology in the fight against this key pest affecting cotton production for years. Equipped with genes of the Bt bacterium, Bt cotton plants produce endotoxins that are lethal to some Lepidopteran pests, such as the PBW (Naik et al. 2005; Subramanian and Qaim 2009; Kathage and Qaim 2012; Kaviraju et al. 2018; Khan et al. 2018). However, the abrupt return of the major cotton pest that Bt technology aimed to prevent has alarmed scientists and policy makers alike and set off a renewed debate regarding the longevity of the technology (Mohan 2017; Naik et al. 2018; Fand et al. 2019; Friedrich et al. 2022; Najork et al. 2021). An earlier wave of this debate occurred when the first Bt cotton generation (Bollgard I) was declared ineffective in 2009 and was soon after replaced by its successor (Bollgard II), which was authorized in India in 2006. Upcoming resistance of the target pest against the single-gene Bt cotton variant was previously reported, and obsolescence was suspected (Haribabu 2014; Naik et al. 2018). The recent return of the PBW has now retriggered these previous concerns. A critical reexamination of the role of Bt technology, especially in regard to cotton farming households' (HHs) altered vulnerability contexts and the broader related political-economic implementations, is therefore urgently needed.

Our aim is to provide such a reassessment by means of a political-economic discussion of the recent technological failure of Bt cotton in India. Therefore, we follow Flachs (2019a), who postulates a lack of critical understanding of the recurrent crises of Indian Bt cotton cultivation.

[26] Aside from the PBW (*Pectinophora gossypiella*), the bollworm complex includes the American bollworm (*Helicoverpa armigera*) and the spotted bollworm (*Earias vitella*).

We present the results of a representative survey of vulnerabilities among Bt cotton-farming HHs in Telangana, India (n = 457). While we addressed this issue in a prior qualitative study (Najork et al. 2021), we now aim to contextualize the newly emerged vulnerability context in the broader political economy. We thus tie our vulnerability-related findings to the concept of accumulation by dispossession (Harvey 2005) and argue that Bt cotton is a neoliberal technology with an inherent *sociobiological obsolescence*, which leads to a successive dispossession of economically weak farmers and enables the appropriation of agricultural assets by others. This ultimately reproduces prevalent hegemonic structures in a Gramscian sense (Brown 2019; Jakobsen 2018b) and drives capital to further concentrate in India's cotton-producing sector.

6.2 Vulnerability, technology and capitalism

In this study, we provide an analysis of the shift in the vulnerability context of cotton-farming HHs in India due to the recent return of PBW infestations. Vulnerability describes the exposure of HHs to contingencies and stress and the difficulty of coping with and adapting to them (Watts and Bohle 1993; Adger 2006). Given the background of our study, this concept allows us to examine the state of susceptibility of farming HHs to harm from exposure to PBW pest infestations and from the absence of capacities to cope with and adapt to this altered situation (Adger 2006, p. 268). Our vulnerability analysis involves a discussion of the following four key parameters: HH exposure and susceptibility to PBW infestations and their coping and adaptation mechanisms (Birkmann 2006; Füssel 2007; Weichselgartner 2016). In terms of exposure, we address the nature and degree to which a HH experiences environmental and socio-economic stress, which can be characterised by the frequency, magnitude, and duration of the stress (Adger 2006, p. 270), and under susceptibility, we discuss the extent to which PBW infestations affect the studied HH economies (Weichselgartner 2016, p. 20). In terms of coping, we describe the potential of HHs to immediately deal with and overcome stress related to PBW infestations by means of available resources, knowledge and skills, while in terms of adaptive capacities, we examine HHs' abilities to learn from past experiences and to actively expand their range of options for coping in the near future (Keck and Sakdapolrak 2013, p. 10). Specifically, the following capabilities describe the resilience of a HH system: the capacity to persist when confronted with disturbance; the ability to adapt to political, social, and environmental changes; and the ability to transform to enhance future functionality (Keck and Etzold 2013, p. 77; Folke et al. 2010).

As Watts and Bohle (1993) suggested in their landmark article, vulnerability analyses should account for the structural properties of the political economy, which decisively precipitate livelihood conditions and HHs' capacities to withstand crises. In this study, we take this consideration seriously. We use the vulnerability concept as a heuristic framework to order our results and discuss our findings against the backdrop of the current neoliberal regime, which provides a larger political-economic context in India at present.

Neoliberalism generally involves the politically initiated restructuring of institutional frameworks for intensified marketization and commodification (Harvey 2007; Brenner et al. 2010). Until the early 2000s, neoliberalism was mostly viewed as a totalizing hegemonic structure characterized by a fixed set of attributes with predetermined outcomes that spread across national borders (Ong 2007). In contrast, the contemporary understanding of neoliberalism is more like that of a variegated nexus of constitutively uneven but cumulatively transformative processes and mechanisms (Peck and Theodore 2007; Brenner et al. 2010). Brenner et al. (2010, p. 198) therefore argue that there is no “single worldwide neoliberal regime” but rather hypothesize that successive waves of neoliberal transformation occur at all spatial scales, culminating in “distinct yet interdependent pathways of neoliberalization”. Accordingly, we understand neoliberalism as a logic of governing that migrates and is selectively taken up in various political contexts (Ong 2007). In this paper, we particularly call attention to the role of technology as one mechanism of the ongoing processes of neoliberalization.

Harvey (2003) describes neoliberal societies as those that tend to follow the belief that there is a technological solution “to whatever problems they are encountering” (Harvey 2003, p. 3, 2007)—a ‘technological fix’. In our case, Bt cotton represents one such neoliberal technology. Advocates have argued that Bt technology not only protects farmers from infestations on an individual scale but also leads to economic growth in the agricultural sector and rural development in India as a whole (Qaim 2003; Kathage and Qaim 2012; Choudhary and Gaur 2015; Veettil et al. 2016). However, as Harvey (2003, 2007) shows, technological fixes in general do not truly serve to actually solve the aforementioned economic or societal problems but rather enable further accumulation of capital. In this context, corporate strategies emerge to create new markets that are primarily dedicated to producing new demands for products that hitherto have not existed (Harvey 2007, p. 69). To keep the machinery of creating demands alive, predetermined breaking points are integrated into products such as consumer electronics, clothing, and automobiles, causing obsolescence and, thus, ensuring long-term sales of ever-new products through a shortened product life cycle (Haribabu 2014). The use of inferior materials, for example, can initiate breaking points that force consumers to repeatedly buy new products, while those in prior use can be repaired instead (Haribabu 2014). While this obsolescence is planned and technological in essence, Haribabu (2014) argues that the seed industry also employs such strategies.

Building on Haribabu (2014), in this paper, we argue that Bt cotton seed technology has an underlying obsolescence, which we identify as a *sociobiological obsolescence*. We use the term sociobiological because the production and use of Bt technology is socially constructed and embedded while concurrently being entangled with biological influences. As the socially anchored technology is rendered obsolete with every newly emergent resistance in the target pest, it is conditional on basic biological developments. The underlying processes that cause Bt technology to become obsolescent, therefore, markedly differ from those in the manufacturing industry in that they depend on biological qualities. However, we argue that the outcome, i.e., the increased pressure on consumers to buy ever-new products shows clear parallels. While we thus renounce the labelling of this obsolescence as deliberate and hence distinguish it from a 'planned' obsolescence, we suggest that the technological design was flawed from the start, as it has always been dependent on evolutionary biological factors and therefore includes an inherent obsolescence.

In this way, we see the obsolescence built into contemporary Bt technology as a key driver of what Harvey (2005) called 'accumulation by dispossession'. Harvey (2005) draws upon Karl Marx's (1967, p. 714) notion of 'primitive accumulation' but focuses on the new strategies developed in capitalist countries under neoliberal governments aiming to transfer public wealth into an increasingly concentrated private sector. Marx used the concept of primitive accumulation to grasp the precondition of capitalism marked by late sixteenth-century English enclosures in which elites appropriated peasant land to graze sheep and engage in the highly profitable wool trade, while peasant farmers became landless and, thus, were obliged to engage in wage labour (Perelman 2000; Di Muzio 2007). With his reading, he turned especially against the bourgeois mythologies concerning capital being generated through the frugality of the elite, replacing it with a history of violent expropriation, colonial expansion and racialized enslaved labour (Di Muzio 2007; Burnard 2019). However, for Marx, the 'historical process of divorcing the producer from the means of production' was confined to a particular (if indefinite) period before the capitalist accumulation regime fully locked in. In contrast, according to Luxemburg (2003) and Harvey (2005), the violent expropriation of production resources represents a process that is still taking place in capitalist economies to date (Glassman 2006; Castree 2007; Carroll 2017; Rosa et al. 2017). The removal of agricultural producers from the countryside, especially in peripheral regions, and the consolidation of more privatized control over resources remain very important processes today, affecting billions of people, especially in the Global South (cf. Luxemburg 2003). As Harvey shows, primitive accumulation—or its present form of accumulation by dispossession—is an inherent and continuous element of current capitalist societies, and its range of action extends to the entire world (cf. Luxemburg 2003; Glassman 2006; Carroll 2017).

What accumulation by dispossession essentially does is create crises and enforce a devaluation of assets, which can later be seized via capital and turned to profitable use (Harvey 2005, p. 149ff). Thus, recurring crises constitute both an essential feature of capitalism itself and a major instrument for accumulation by dispossession. The state, with its hegemonic licence to define what is legal and what is not, is not simply an accomplice in this process. Rather, the state plays an active role in coordinating new forms of dispossession, in providing normative frameworks that legally support it, and in legitimizing the process of creating dispossessed social actors in the name of growth and progress (Cáceres 2015, p. 117).

6.3 Methodology

Among Indian cotton-producing states, Telangana ranks third, after Gujarat and Maharashtra, with regard to cotton area and production. In the 2016/17 season, the planting area of cotton in the state was 1.4 Mha, and production reached 4.8 million bales, with a yield of 579 kg/ha (CCI 2018, p. 3). This area is in the southern zone of Indian cotton production and is primarily rainfed (Gaurav and Mishra 2012; Choudhary and Gaur 2015). We chose Telangana because it provides a valid perspective of southeastern Indian rainfed cotton production that contrasts with the perspective of profiting northern irrigated Bt cotton growing states (Gutierrez et al. 2015). In this study, we built upon earlier qualitative research that we conducted in the state and, thus, aimed to complement those findings with the results of a quantitative survey (Najork et al. 2021).

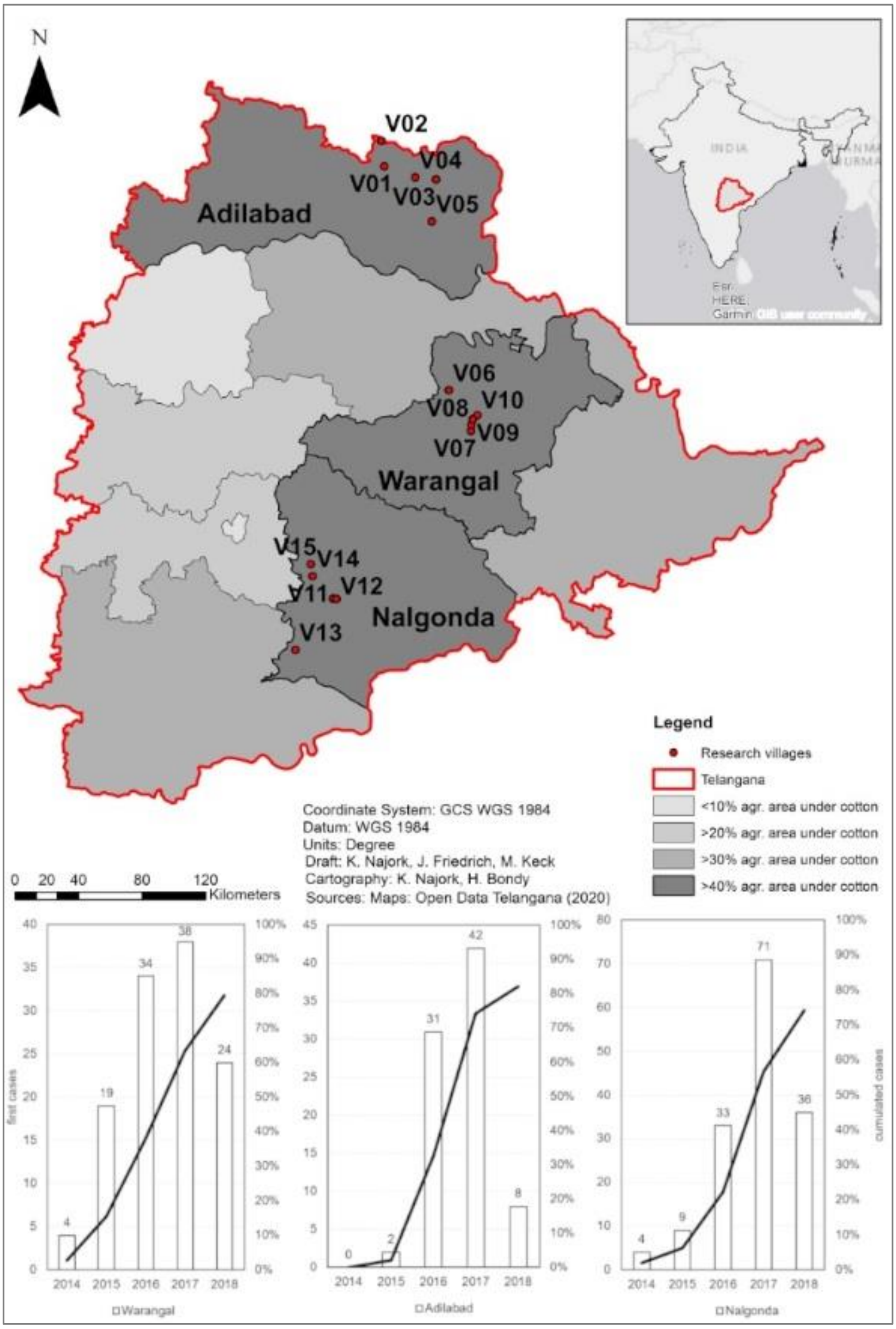
6.3.1 Data acquisition

We conducted fieldwork in August and September 2019 in 15 randomly selected villages in the three major cotton-producing districts of Telangana, i.e., Adilabad, Warangal, and Nalgonda (Fig. 1). We selected these three districts because they are ranked highest in terms of total cotton area, percentage of area under cotton cultivation to total area sown, and output (Government of Telangana 2017, pp. 118–120).[27] For each district, we determined the three *mandals*[28] with the highest percentage of area under cotton cultivation to the total area sown according to the district's agricultural handbook, which we acquired in person from the relevant agricultural offices (Agricultural Office Adilabad 2014; Agricultural Office Warangal 2014; Agricultural Office Nalgonda 2015). In each *mandal*, we randomly selected five villages with 1000 to 6000 inhabitants via automated computerized sampling and calculated the sample sizes for each individual village (Table 1) on the basis of available population data from 2011

[27] As we relied on the decennially published Indian census data for our survey sampling method and, thus, used the 2011 census data for our sampling, it was inevitable that all the data used in the sampling procedure refer to the erstwhile districts and village structures of Telangana before they were restructured in 2016.
[28] A mandal is the administrative division subordinate to a district.

(Government of India 2011).[29] We ultimately identified the HHs for the interviews by means of random walks. Each village was defined in its erstwhile boundaries in consultation with local *sarpanches* and then divided into commensurate areas on the basis of satellite images. Along the random walks, we targeted every other house and alternated starting at the village centre or outskirts, aiming to take into account geographically replicated socioeconomic backgrounds (e.g., caste or class) and to avoid biases in the results. A total of 457 HHs were interviewed through their respective HH heads, which resulted in sex- and agewise bias, since the vast majority of HH heads was male and 30 years or older. To avoid distorting effects arising from interventions in the interviews by neighbours or relatives, we interviewed the identified HH heads individually. All interviewees had grown cotton within the last 5 years.

[29] Our sampling procedure rests on population figures presented in the 2011 census. These figures might deviate from actual proportions as recent population dynamics may have resulted in changes in some of the village sizes.



[Publication 2] Figure 1: Cotton production, study sites, and PBW infestation in Telangana

We were accompanied by six Telugu-speaking surveyors who were responsible for data collection. All of them received specific training beforehand on both the thematic focus of the study and its quantitative methodology and took part in test interview scenarios. An intense preparatory phase allowed for an in-depth mutual understanding between the surveyors and the rest of the study team. A pretest was given in two Warangal villages not included in the sample to ensure proper questioning and handling of the questionnaire. The questionnaire included open- and closed-ended questions and Likert-scale, single-choice, and multiple-choice questions. The thematic focuses of the questions included sociodemographic and agriculture-related data, both at the HH level, as well as data on the cultivation of Bt cotton, PBW, refuge crops, and access to knowledge and markets. Given our theoretical scope, for this study, we consider thematic sections concerning the cultivation of Bt cotton and PBWs and focus on HHs' economic assets.[30]

As our vulnerability study relies on farmer recall, it is also possibly biased in regard to data that are related to past phenomena. Exaggeration, underestimation, and misremembering facts are common challenges in social sciences research. However, since we did not ask for specific agronomic figures such as yield, prices or income, which farmers often have difficulties supplying (Flachs 2019b), this approach allowed us to record larger trends in Bt cotton production from the farmers' perspective. With this study, we therefore do not aim to and cannot portray aggregate production statistics or yield averages; rather, we attempt to expose the effects of Bt cotton technology on marginalised farming HHs by depicting the mechanisms of dispossession on a micro scale. While we are aware that a cohort study would provide a much more nuanced picture and allow us to track changes over time, it is in the very nature of the matter that our study covers only a short time frame, since the return of the PBW is a recent phenomenon.

[Publication 2] Table 1: Sample Composition

District	**Mandal**	**Village**	**Population**	**No. HHs**	**n**
Adilabad	Wankdi	1	1009	223	10
Adilabad	Wankdi	2	1854	405	18
Adilabad	Kagaznagar	3	2665	687	31
Adilabad	Kagaznagar	4	2304	575	26
Adilabad	Bhimini	5	1292	344	16
Warangal	Parkal	6	3261	853	38
Warangal	Duggondi	7	3729	1026	46
Warangal	Duggondi	8	2761	743	33
Warangal	Duggondi	9	2723	730	33
Warangal	Duggondi	10	3305	953	43
Nalgonda	Chandur	11	2907	759	34
Nalgonda	Chandur	12	2147	501	23
Nalgonda	Devarakonda	13	2796	665	30

[30] We are aware of the potential effects of noneconomic resources (e.g., knowledge, social relations, trust) on farmers' vulnerabilities in regard to the reoccurring target pest; however, this aspect is beyond the scope of this article.

Nalgonda	Narayanapu	14	5663	1415	63
Nalgonda	Narayanapur	15	1173	288	13

6.3.2 Data analysis

In our analysis, we calculated the correlations of socioeconomic HH features and basic agricultural characteristics with the impact of PBW pest infestations and recent changes in agricultural production. We examined the frequency distributions of all relevant variables by means of χ^2 tests, whereas sparsely populated categories as well as variables with insufficient overall frequencies (cross-tables with > 20% of cells with expected counts below 5) were excluded. We quantified the identified correlations by Cramer's V (φ) (nominal data; $p \leq \alpha \leq 0.05$) and Spearman's rank (ρ) correlation (ordinal data; $p \leq \alpha \leq 0.05$) coefficients and studied them further on the basis of relevant cross-tabulations (De Lange and Nipper 2018).

6.4 Bt cotton in India

The commercialization of Bt cotton in India has to be observed in the context of the neoliberal economic reforms undertaken in the 1990s. The Indian agricultural sector was restructured, in that state regulations were eased, seed production was privatized, and trade barriers were removed so that agrarian technologies could be accessed more easily from abroad (Glover 2007; Carroll 2017; Flachs 2019a). This restructuring allowed the Indian Maharashtra Hybrid Seeds Company (Mahyco) and the US-based company Monsanto to develop genetically engineered cotton for the Indian market in a joint venture called Mahyco Monsanto Biotech Limited (MMBL).[31] Single-gene Bollgard I (Cry1Ac) and double-gene Bollgard II (Cry1Ac and Cry2Ab) cotton were commercialized in 2002 and 2006, respectively[32] (Ramamurthy 2000; Scoones 2008; Sadashivappa and Qaim 2009; Flachs 2019a). Given the unprecedented rise in the implementation of this new technology, today, an estimated 95% of the area under cotton cultivation is planted with double-gene Bt cotton (ISAAA 2017).

However, despite its promising implementation rate, the risks and benefits of the technology remain contested (Qaim 2003; Stone 2011; Kathage and Qaim 2012; Choudhary and Gaur 2015; Gutierrez et al. 2015; Kranthi 2015; Veettil et al. 2016; Flachs 2019a; Kranthi and Stone 2020). In particular, agronomic scholars attribute successes in Indian cotton production in the

[31] As outlined by Glover (2007, p. 123), this alliance was "a convenient mechanism to facilitate Monsanto's introduction of its transgenic traits to the Indian market", as a solitary market entry had previously failed in 1993.

[32] The third herbicide-tolerant (HT) generation of Bt cotton technology (Bollgard III) is not (yet) commercialized in India. However, its unauthorized cultivation has recently sparked a major controversy among cotton farmers and authorities in the country (ISAAA 2017). The risk of resulting herbicide treadmills in this regard was indicated by Stone and Flachs (2017).

early 2000s, that is, increased yields and decreased pesticide use, to the technology, thus declaring it an effective weapon against the Indian agrarian crisis (Sadashivappa and Qaim 2009; Kathage and Qaim 2012; Veettil et al. 2016). Other studies, however, accredit these positive agronomic trends to a plethora of factors and emphasize the high variability of the socioeconomic effects of the technology and its inseparability from specific agricultural practices (Glover 2010; Gutierrez et al. 2015; Kranthi 2016; Flachs 2019a; Kranthi and Stone 2020).

Early studies largely based on pre-2008 data argued that Bt cotton technology led to higher effective yields and even “strongly outperformed” its conventional equivalent (Kathage and Qaim 2012; p. 1; Naik et al. 2005; Sadashivappa and Qaim 2009; Subramanian and Qaim 2009; Choudhary and Gaur 2015). Consequently, Bt cotton is claimed to have contributed to “positive economic and social development”, as farmer profits are reported to have increased accordingly (Kathage and Qaim 2012, p. 1; Sadashivappa and Qaim 2009). As this was believed to have led to higher living standards for adopting HHs, Bt cotton was by some denoted as a pro-poor technology (Sadashivappa and Qaim 2009; Kathage and Qaim 2012; Yadav et al. 2018). Later studies, however, found lower contributions of the technology to the positive effects in recent cotton production figures and instead attributed these positive overall effects to a multitude of agrarian factors, most prominently the use of hybrid seed, the expansion of irrigation facilities, and increases in fertilizer application (Glover 2010; Stone 2011; Gutierrez et al. 2015; Kranthi 2016; Flachs 2019a; Kranthi and Stone 2020). Accordingly, they question the proclaimed successes of Bt cotton in rural poverty reduction (Glover 2010) and report negative social (erosion of farmers’ knowledge) (Stone 2007; Flachs 2019a) and ecological side effects (outbreaks of secondary pests, upcoming resistance to the target pest) (Kranthi 2015, 2016; Gutierrez 2018; Flachs 2019a; Tabashnik and Carrière 2019; Kranthi and Stone 2020).

Recently, the debate was reignited after unusually high levels of PBW infestation were reported for the states of Gujarat, Madhya Pradesh, Maharashtra, Karnataka, Andhra Pradesh, and Telangana in the *kharif*[33] season of 2015 and after (Mohan 2017; Fand et al. 2019). Progressive increases in the survival rate of PBW larvae within cultivated Bollgard II hybrids have been reported; these increases are viewed as indicators that larvae have developed resistance against the endotoxins produced in cotton plants (Mohan 2017; Naik et al. 2018; Fand et al. 2019). Fand et al. (2019, p. 313) estimated related yield losses of up to 30% per farming HH for the state of Maharashtra. As these studies have helped to clarify, after its hiatus lasting almost two decades, the PBW has returned to the cotton belt of central and southern

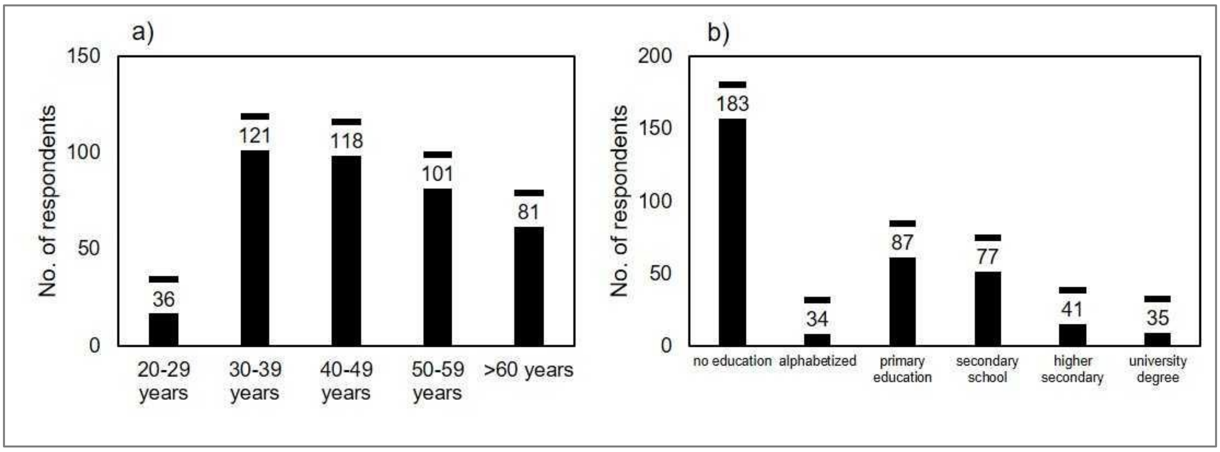
[33] In Telangana, depending on the species planted, crops are grown in two different seasons. The season of *kharif* (monsoon season), in which cotton cultivation takes place, refers to the autumn season and begins in June. The season of *rabi* refers to the winter and usually begins after the *kharif* crops are harvested.

India (Kranthi 2015; Mohan and Sadananda 2019; Tabashnik and Carrière 2019)—a development that fundamentally changes the situation for Bt cotton-farming HHs in this area. Against this backdrop, an analysis of the newly evolved vulnerabilities resulting from pests returning to Bt cotton farms is highly relevant.

6.5 PBW pest infestations and their impacts on cotton-farming HHs in Telangana

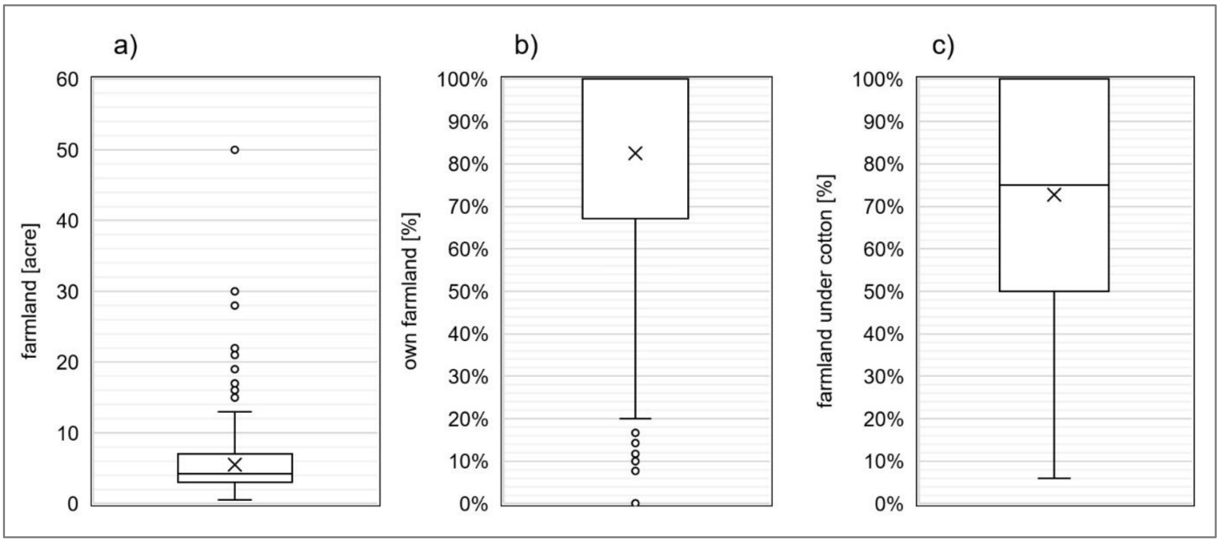
6.5.1 Background information on the studied cotton-farming HHs

The basic figures of our study sample are as follows. Of the 457 interviewed HHs, 446 were led by a male and 11 by a female. Figure 2 shows the age structure of the HH heads and their education levels. The interviewed HHs had an average size of 4.3 people, of which 2.0 people contributed to HH income. In addition, 2.2 generations on average were accommodated in the HHs.



[Publication 2] Figure 2: a) Age structure of the HH heads (n=457); b) highest education level of the HH heads (n=457)

The mean farmland size of the interviewed HHs amounted to 5.5 acres, with a minimum of 0.5 acres and a maximum of 50 acres (n = 456). Of these, 4.1 acres on average were owned, which corresponds to 83% of the total cultivated farmland, with a minimum of zero and a maximum of 100% owned farmland and slight differences at the district level (Adilabad, 74%; Nalgonda, 81%; Warangal, 88%) (n = 456). Cotton cultivation occurred on 4.0 acres on average (73%), with noticeable differences at the district level (Warangal, 56%; Adilabad, 77%; Nalgonda, 89%) (n = 453) (Fig. 3).

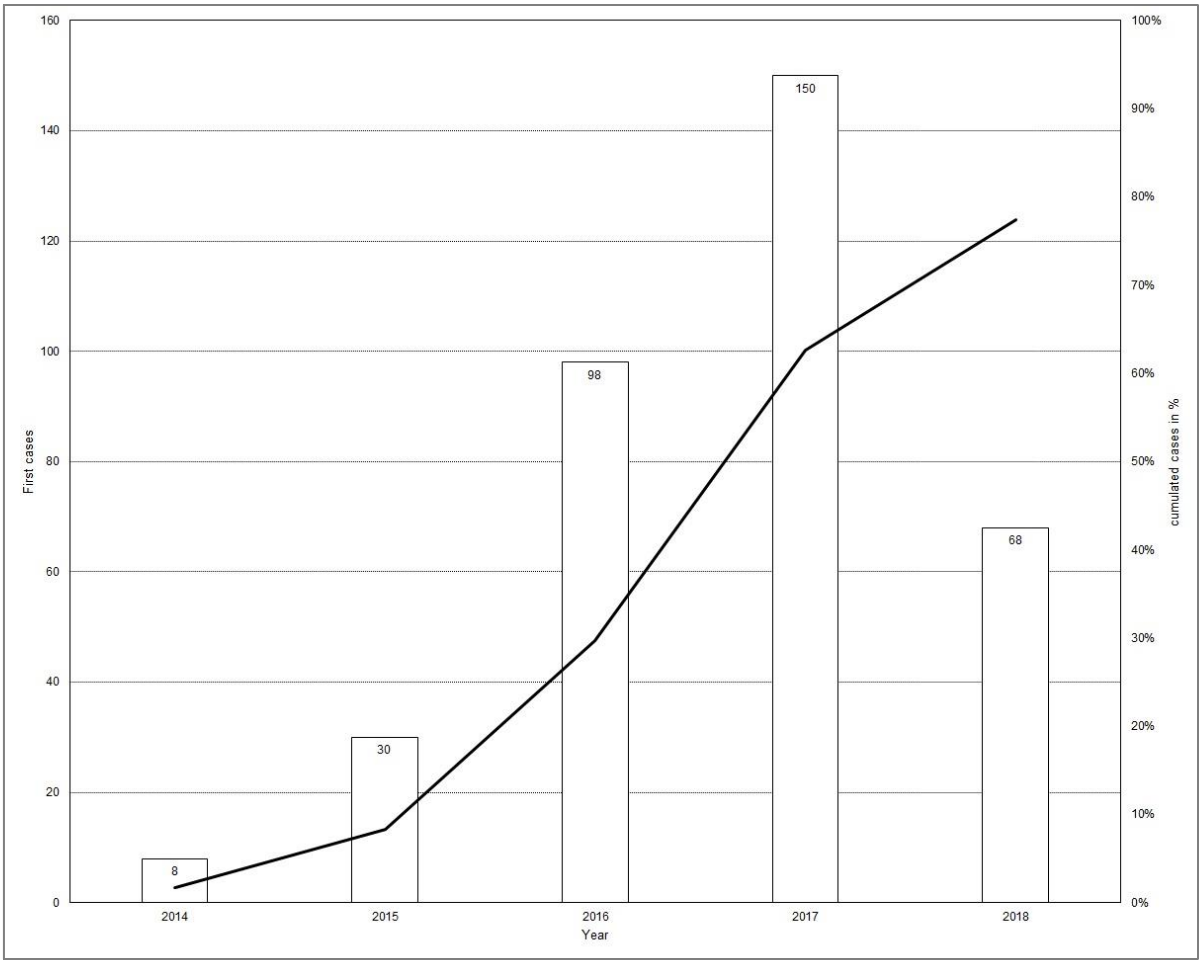


[Publication 2] Figure 3: a) Overall farmland (n=456); b) owned farmland (n=456); c) farmland under cotton cultivation (n=453)

The vast majority of interviewed HHs (86%) had grown Bt cotton for an average of 8 years per HH. The remaining interviewees (14%) answered that they were unaware of whether they were growing Bt cotton, with the exception of one HH that reported growing non-Bt cotton. Examples of seed brands used ranged from Nuziveedu (e.g., *Bhakti*, *Mallika*) and Rasi (*659*) to Aditya (*Moksha*). One per cent of the interviewed HHs stated that they were growing illegal, HT Bollgard III cotton.

6.5.2 Exposure of cotton-farming HHs to PBW pest infestations

Our results confirm that PBWs have returned to cotton fields in Telangana, as 80% of all interviewed HHs affirmed having faced PBW pest infestations in their fields during the past 5 years (n = 457). Of these, 96% reported the first appearance of this pest within the past 5 years, as our interviewees reported a total of 354 first cases of PBW infestation from 2014 to 2018 (n = 367). The largest share of PBW occurrences was found in Adilabad, at 84%, and the smallest was found in Nalgonda, at 77% (81% in Warangal). The low degree of variation in the number of HHs experiencing PBW infestations indicates little geographical variability in PBW infestations in the three districts. As shown in Fig. 4, the number of first cases of PBW pest infestation increased drastically from 2014 (eight first cases), peaking in 2017 with a total of 150 first cases, after which the number decreased in 2018 to a total of 68 new cases.

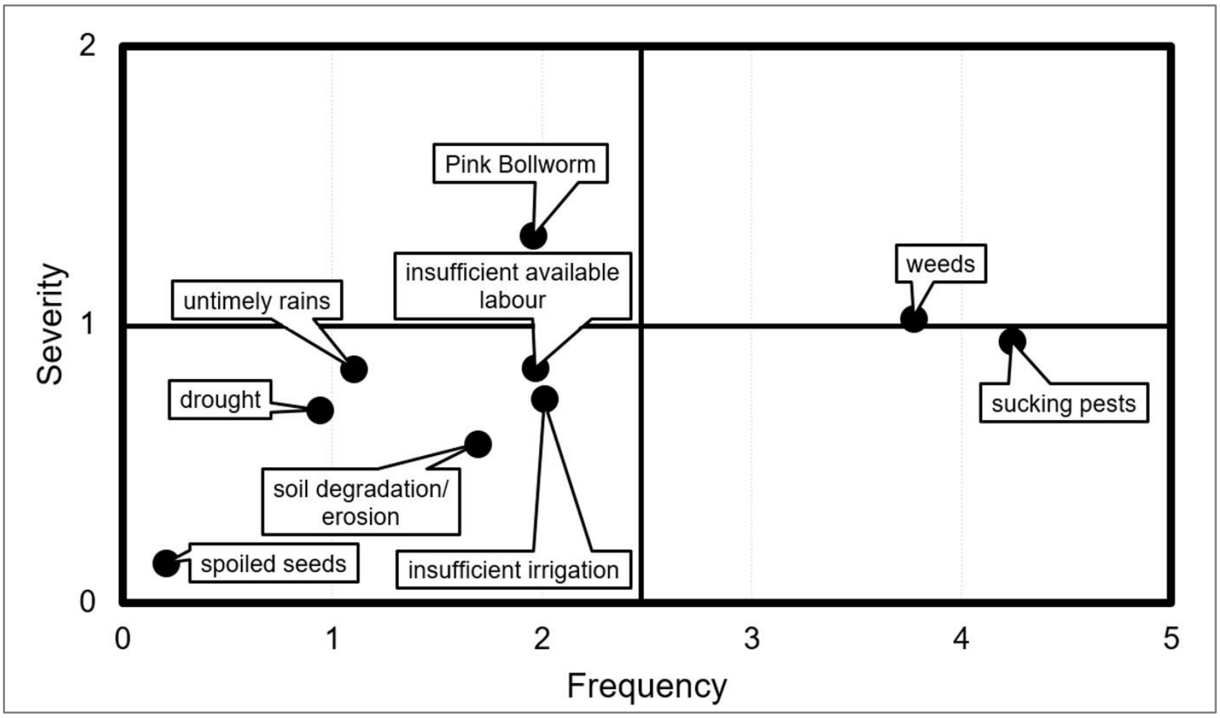


[Publication 2] Figure 4: Temporal distribution of the first reported cases of PBWs (line graph, n=457; bar graph, n=367)

On average, PBW pest infestation occurred within 1.95 years per HH in the period between 2014 and 2019; Adilabad (2.07) and Warangal (2.06) showed the highest frequencies, while in Nalgonda, lower numbers of infestations were reported on average (1.77). With a mean impact of 1.32, where 0 represents no impact and 2 equals a severe impact, these recent pest infestations were evaluated as having moderate negative impacts ranging from 1.29 in Nalgonda and 1.30 in Warangal to 1.42 in Adilabad.[34] The interviewed HHs perceived PBW infestation as the most severe agricultural problem among all other relevant problems related to Bt cotton production (Fig. 5). The lower frequency value may be explained by the recency of the pest's reemergence as an agricultural problem. Our findings therefore suggest that PBW infestation is classified as a low-frequency/high-impact risk (Keck et al. 2012). As shown in Fig. 5, all other threats were perceived as less severe and, thus, fell within the range of low-

[34] The grading was based on the perceptions of the farmers surveyed. The Likert scale values (low, moderate, severe) therefore represent relational values, where low impacts could represent the observation of a problem without further consequences, moderate impacts could represent noticeable losses in yields, and severe impacts could be interpreted as total yield loss, e.g., through the practice of slashing and burning entire harvests (Najork et al. 2021).

frequency/low-impact risks (for example, spoiled seed, untimely rains, insufficient available labour), high-frequency/low-impact risks (sucking pests), or high-frequency/high-impact risks (weeds).



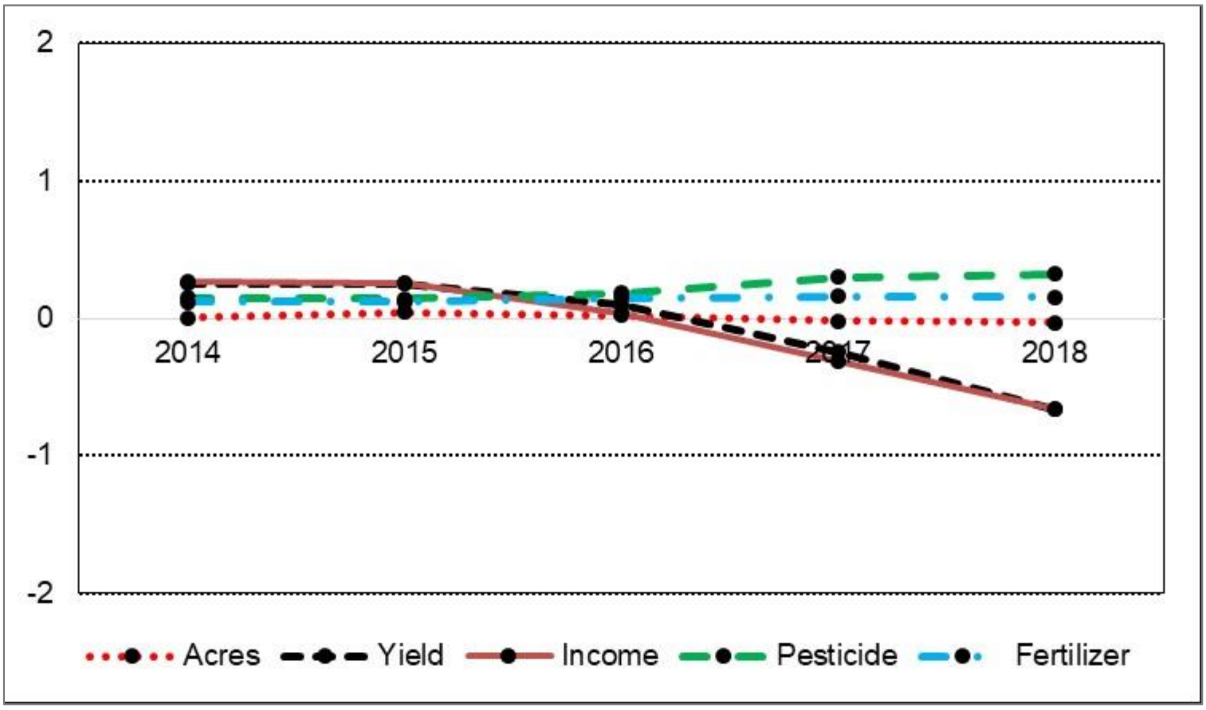
[Publication 2] Figure 5: Frequency and severity of agricultural threats in the past five years (Average Likert scale for severity from 0 [no impact] to 2 [severe impact]; for frequency, from 0 [no occurrence] to 5 [occurred five times in five years] [n=448-454, variation according to the frequency and severity of individual threat parameters])

6.5.3 Susceptibility of cotton-farming HHs to PBW pest infestations

In accordance with the recorded first cases of PBW pest infestation in our sample, farmers' cotton yields and related incomes showed a clear negative trend from 2015 onwards. By using a range from a 'strong increase' (2) to a 'strong decrease' (− 2) in yields and income compared to those in the previous year, Fig. 5 shows a slight increase in yields and cotton-related income for 2014 (*0.26*) and 2015 (*0.25*), whereas it depicts a continuously declining trend from 2016 (yield, *0.01*; income, *0.03*) onwards (yield in 2017, − *0.24*; income in 2017, − *0.31*; yield and income in 2018, − *0.66*).

As shown in Fig. 6, the usage of pesticides and fertilizers increased slightly from 2014 to 2018 (pesticides: *0.15* in 2014–2015, *0.32* in 2018. Fertilizers: *0.12* in 2014–2015, *0.16* in 2017, *0.15* in 2018). Notably, HHs owning less than 50% of their farmland disproportionately increased their pesticide usage, while those owning more than 50% of their farmland decreased in the same manner—a trend that continuously intensified between 2016 and 2018, as increasing correlation coefficients showed (2016: $\rho = -0.127$, $p = 0.035$, $n = 376$; 2017: $\rho = -0.159$, $p =$

0.005, n = 386; 2018: *ρ = − 0.164, p = 0.004, n = 388*). The cotton-related acreage, in contrast, remained almost the same (*0.01* in 2014; *− 0.03* in 2018).

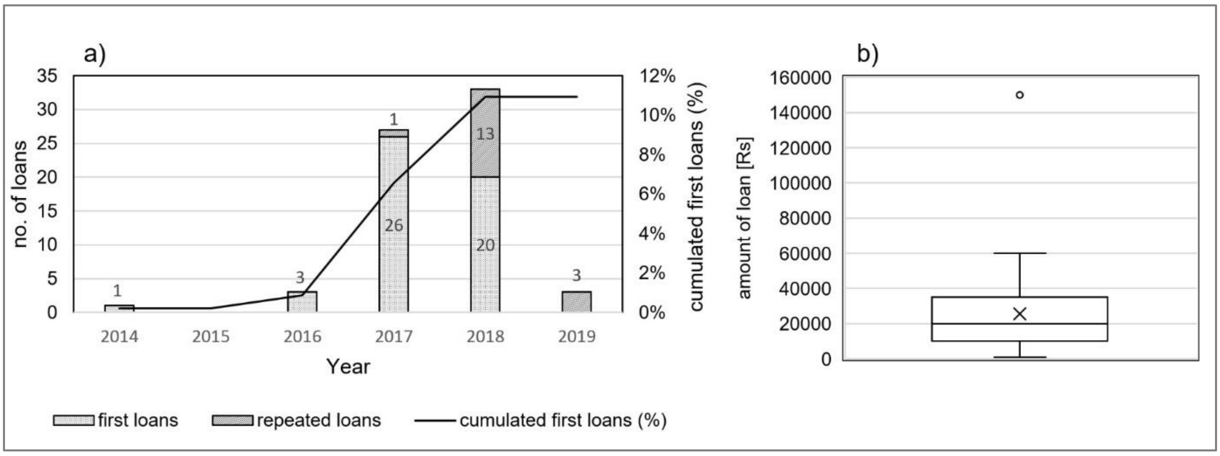


[Publication 2] Figure 6: Acres, yield, income, pesticide usage, and fertilizer applications in 2014-2018 compared to those in the previous year (average Likert scale from -2 [strong decrease] to +2 [strong increase]) (n=341-356, variation according to parameter and year)

6.5.4 Coping mechanisms of cotton-farming HHs in response to PBW pest infestations

As a direct response to the return of PBW pest infestations, 11% (n = 457) of the interviewed HHs had to take loans during the previous 5 years. It is worth noting that 24% of the respondents did not answer this question, which may be associated with its high degree of sensitivity. In terms of district comparisons, Nalgonda shows disproportionately high values; 14% of the interviewed cotton farmers had to take loans related to the reoccurrence of PBW pests, whereas in Adilabad and Warangal, these numbers were slightly lower (10% and 9%, respectively). At the village level, the respective figures vary from 0% (village 10 in Warangal) to 31% (village 15 in Nalgonda).

The amount of loans ranged from 1000 Rs to 60,000 Rs, with a clear outlier of 150,000 Rs and a clear distribution, as shown in Fig. 7. To access these loans, in 83% of the cases, our interviewees referred to informal sources, such as landlords or commission agents, while only 17% answered that they had obtained loans from the formal system (n = 59). 30% of those HHs who took a loan once (n = 50) had to take loans at least once again and up to four times. More than two-thirds (68%) of the HHs that took a loan related to the target pest were still indebted (n = 50). Notably, the share of still-indebted farmers in Warangal was noticeably lower (47%) than that in the other two districts (Adilabad, 80%; Nalgonda, 78%).



[Publication 2] Figure 7: a) Temporal distribution of loans directly related to PBW infestation (line graph, n=457; bar graph, n=67); b) Distribution values of loans taken from 2014-2019 (n=57)

Figure 7a shows that the total number of loans taken has increased throughout the past 5 years, increasing rapidly in 2017 (27 cases), peaking in 2018 (33 cases), and decreasing again in 2019 (three cases), resulting in a total of 67 cases (n = 50). This gradient fits well with the counted cases of PBW pest infestations among our studied farming HHs, although the procurement of loans lags 1 year behind. Furthermore, we found that the number of repeated loans increased noticeably (Fig. 7a). Again, this surge peaked with a time lag of yet another year, indicating farmers' increasing difficulties in coping with the PBW infestation shock.

A rarely pursued coping strategy involves asking seed companies for compensation. Only 7% (n = 274) of the interviewed HHs asked for compensation, and only 2% actually succeeded. Almost two-thirds (64%) of the HHs that did not ask for compensation reasoned that there was no prospect of success and, thus, refrained from trying to obtain compensation. Nearly one-third of the respondents (31%) answered that they were not interested in trying or were not aware of this possibility.

6.5.5 Adaptive capacities of cotton-farming HHs in dealing with PBW pest infestations

Our respondents changed their agricultural practices in response to the returned PBW pests. This change varied among the surveyed villages and was thus underlined by a strong correlation coefficient with HH villages of *0.306* (φ), with a p value of *0.006* (n = 330). Moreover, this change was moderately correlated with the frequency ($\varphi = 0.250, p = 0.000$) and severity ($\varphi = 0.238, p = 0.000$) of PBW outbreaks (n = 329). According to cross-tabulations, farmers avoid changing their production patterns with low frequency and perceived severity levels of PBW pest infestations, but they change their practices in response to more frequent PBW infestations and a higher perceived impact. As such, altered agricultural practices were mainly found in response to severe levels of perceived pest infestation impacts.

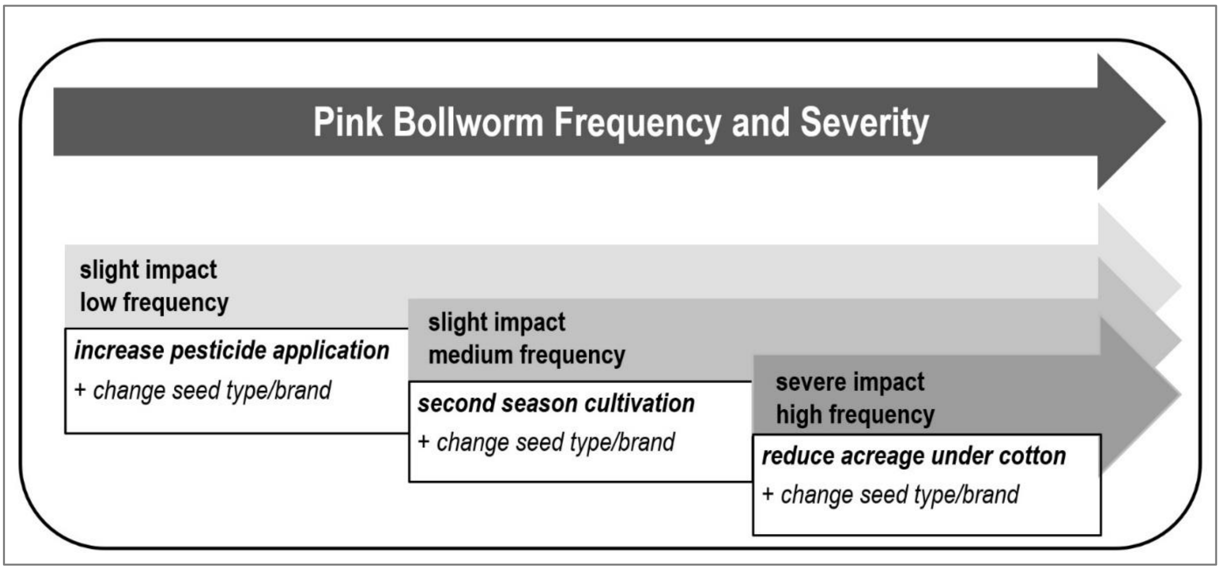
Overall, 33% (n = 350) of all interviewed HHs altered their agricultural production patterns, of which 36% changed their seed type or brand, 35% increased their usage of pesticides, and 29% reduced their cotton acreage. Additionally, 25% of the respondents (n = 372) reported growing a second crop during the following *rabi* season, which was usually maize (92%). Correlations and cross-tabulations suggest a distinct sequence pattern of succession regarding these adaptive strategies contingent on the impact of PBW pest infestations; while interviewees tended to increase their usage of pesticides when there was a lower frequency (1–2) of PBW pest infestations, they more often reduced their acreage under cotton when there was a higher frequency (3–5) of PBW pest infestations (Fig. 8). Similarly, the interviewed HHs increased their application of pesticides when there was a slight perceived impact of PBW pest infestations but reverted to a reduction in acreage only when there was a severe perceived impact (Fig. 8). Second-season cropping was implemented when the perceived severity ($\varphi = 0.226, p = 0.000$) and frequency ($\varphi = 0.337, p = 0.000$) levels of PBW infestations (n = 371) were moderate. Changing seed type or brand, in contrast, was found to be adopted in addition to implementing the other strategies; however, these changes were not distinct adaptive strategies.

These findings indicate that respondents tended to avoid acreage reduction and that this strategy served as a last resort to address increasingly frequent and severe pest infestations. Moreover, both the perceived severity ($\varphi = 0.291, p = 0.000$) and frequency ($\varphi = 0.251, p = 0.000$) of PBW pest infestations showed a moderate correlation with the manner of change in the mentioned agricultural practices (n = 347). Altogether, farming HHs moved from employing strategies of agricultural intensification to those of agricultural diversification. The latter strategies therefore stand out as being particularly important regarding the development of resilience to PBW infestations.

Of our interviewees, 63% (n = 457) responded that they grow other crops in addition to cotton, which included paddy (44%), turmeric (18%), maize (14%), or pulse (7%) crops (n = 287). However, the cultivation of additional crops varied widely among the districts, from 28% in Nalgonda to 72% in Adilabad and 87% in Warangal.[35] Moreover, the diversity of additionally

[35] This geographical difference in regard to agrobiodiversity is striking, as other researchers have reported the cultivation of additional crops to be a common smallholder strategy (Flachs 2015; Flachs and Stone 2019; Kannuri and Jadhav 2018; Krishna et al. 2016). We suspect water to be the decisive factor here: first, we see water to be a limiting factor in regard to adaptive strategies of agricultural diversification (Evans and Giordano 2012; Gutierrez et al. 2015; Raizada et al. 2018; Kuchimanchi et al. 2019), and second, we found correlations between district and water availability, both of which are described below. A thorough discussion on this is, however, beyond the scope of this paper.

cultivated crops differed among the three districts; while the largest share of crops aside from cotton consisted of paddy in Nalgonda and Adilabad (72% and 60%, respectively), additional crop production appeared to be more diversified in Warangal (34% paddy, 26% turmeric, 22% maize) (n = 287). These findings were also confirmed via correlation analysis, which showed a strong correlation between the cultivation of other crops and villages in different districts ($\varphi = 0.545, p = 0.000, n = 457; \varphi = 0.584, p = 0.000, n = 457$).

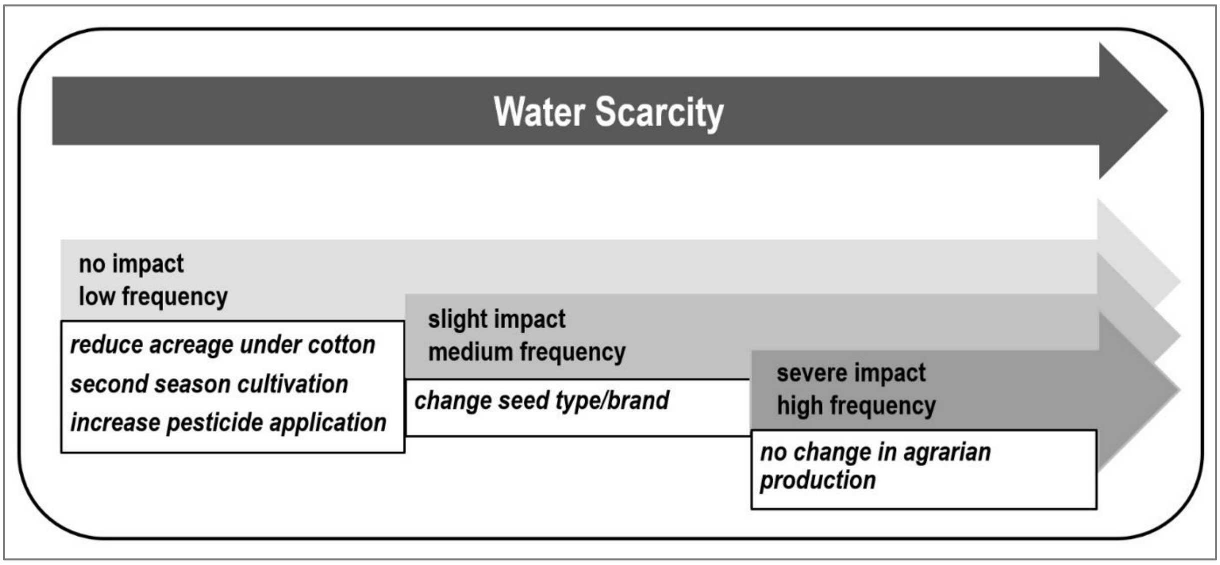


[Publication 2] Figure 8: Influence of PBW pest infestations on agricultural adaptation strategies

6.5.6 Factors limiting the ability of cotton-farming HHs to adapt to PBW pest infestations

Given that we found several significant correlations, the water availability factor needs to be considered a key factor in regard to farming HHs' adaptive capacities to deal with PBW pest infestations. Our findings show that, overall, HHs were significantly more prone to alter their production as long as drought or a lack of irrigation did not appear to be problematic, which were measured in terms of the frequency and perceived severity of the occurrence of these problems (drought frequency: $\varphi = 0.236, p = 0.000, n = 346$; drought severity: $\varphi = 0.231, p = 0.000, n = 345$; insufficient irrigation frequency: $\varphi = 0.193, p = 0.000, n = 344$; insufficient irrigation severity: $\varphi = 0.221, p = 0.000, n = 343$). Our cross-tabulation data indicate that a particular sequence of suitable adaptive strategies exists in regard to the influence of water availability (Fig. 9). As long as the problem of water scarcity is marginal (in terms of its frequency of incidence and perceived severity), HHs tend to reduce their acreage, grow a second crop during the following *rabi* season, or increase their usage of pesticides. In contrast, when the problem of water scarcity is more frequent and intense, HHs tend to change their

seed types or brands. However, when the problem of water scarcity is omnipresent and perceived as being highly severe, HHs tend not to alter their production at all. In particular, the diversification strategy was influenced by the water availability factor. For example, we found significant correlations of second-season cropping and insufficient access to irrigation facilities (frequency: $\varphi = 0.427, p = 0.000, n = 366$; severity: $\varphi = 0.410, p = 0.000, n = 365$).
Regarding the limiting factor of access to irrigation, we found correlations for perceived severity with respect to district ($\varphi = 0.183, p = 0.001$) and village ($\varphi = 0.307, p = 0.000$) (n = 448). This suggests that the adaptive strategies of our interviewed farmers are influenced by heterogeneous localities and climates, as these are crucial factors in determining the likelihood of drought occurrence and farmers' access to irrigation facilities. However, the much higher correlation value at the lower-scale village level suggests that infrastructural asset features determine farmers' access to water even more.



[Publication 2] Figure 9: Influence of water scarcity on agricultural adaptation strategies

6.6 Discussion

We have shown how the return of the PBW has altered the vulnerability of cotton-farming HHs in the state of Telangana. In the following text, we contextualize these vulnerability-related findings by highlighting their political-economic implications. We argue that (1) Bt cotton contains an inherent *sociobiological obsolescence*, which has resulted in technological failure in the sense that protection against PBW infestations can no longer be guaranteed; (2) this technological failure has altered farming HHs' vulnerability context depending on their economic situation, resulting in the dispossession of resource-poor farmers and the possible appropriation of their assets by other actors; and (3) this dispossession ultimately helps the current neoliberal agri-food regime in India become hegemonic as it prepares the ground for achieving “local acquiescence” (Brown 2019, p. 193) among those who are better off.

6.6.1 Sociobiological obsolescence of Bt cotton

Our study provides evidence for the reemergence of PBW pest infestations in the districts of Adilabad, Warangal, and Nalgonda. As the vast majority of our interviewees used Bollgard II seeds and as many as 80% of them affirmed having recently faced PBW infestations, we substantiate other scholars’ findings of evolved biological resistance to the target pest against the currently used second-generation Bt cotton seed (Dhurua and Gujar 2011; Mohan 2017; Naik et al. 2018; Fand et al. 2019; Mohan and Sadananda 2019; Tabashnik and Carrière 2019). We further found that the target pest’s return has implications on a practical level, as interviewed Bt cotton-farming HHs have incurred severe yield and income losses (Naik et al. 2018; Fand et al. 2019; Tabashnik and Carrière 2019). Following the resistance of the PBW to the first generation of Bt seeds in 2009 (Haribabu 2014; Mohan 2017; Naik et al. 2018), our findings suggest that the current variant has also failed.

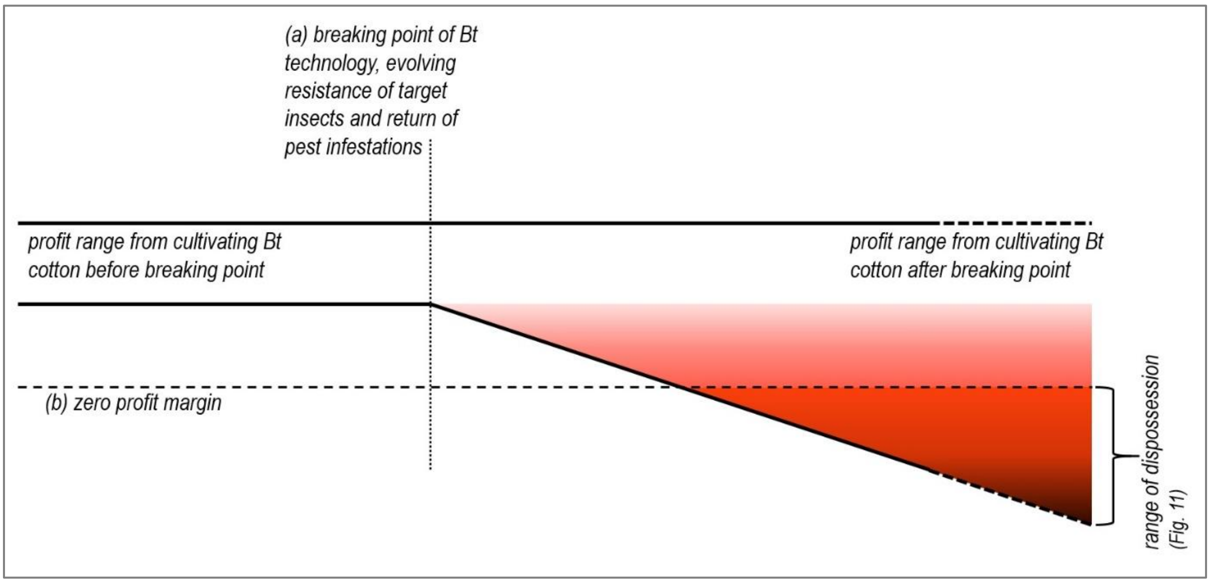
Following Haribabu (2014), we argue that this breakdown of two consecutive generations of Bt cotton shows that a general obsolescence is inherent in the current form of Bt technology. We propose the term *sociobiological obsolescence* to describe this phenomenon. While the technology is socially constructed and embedded, as it is produced in labs and implemented by farmers and its development underlies public political debates, it simultaneously results from biological qualities and is integrated into biological linkages. Due to the biologics of the struggle between pest and host species, Bt technology automatically increases the evolutionary pressure on the target pest, which continually develops new resistance.[36] We argue that this dynamic eventually results in an arms race between farmers equipped with Bt cotton technology and its inherent toxins and target pests, in this case the PBW, endowed with the relevant resistance traits that have evolved as a result of the increased evolutionary pressure. From this, we derive an inherent obsolescence of Bt technology resulting from its embeddedness in both social and biological factors.

In this paper, the term *sociobiological obsolescence* therefore describes the predetermined breaking point that is inherent in Bt technology and has been from the very beginning due to its social and biological embeddedness. We emphasize that due to its biological contingency, this obsolescence is not to be grasped as deliberately initiated and, thus, contrasts with the ‘planned’ obsolescence practices common in the manufacturing industry. However, we

[36] This interdependent and alternating process is described by the red queen hypothesis in the field of evolutionary biology. It assumes that parasites become specialized in regard to certain host species and thereby reduce their fitness (cf. Clay and Kover 1996).

nevertheless see that the outcome of the obsolescence shows clear parallels; i.e., a predetermined breaking point is inherent to the Bt product itself through the technology's social and biological embeddedness in accordance with evolutionary biologics (Fig. 10). This, in turn, increases the pressure on consumers to buy ever-new products—and, hence, the risk of entering a technology treadmill—to maintain the status quo, in this case farmers having to buy new generations of Bt technology (cf. Stone and Flachs 2017). We thus argue that the technology design of Bt cotton was flawed from the start, as it had ab initio been dependent on biological developments.

In addition to early warnings from entomologists and pest management specialists, even seed producers anticipated their products' limited life cycle and suggested that farmers plant non-Bt cotton refuge crops (Kranthi et al. 2017; Mohan 2018, 2020; Tabashnik et al. 2021). This measure, however, did not aim to entirely avoid the breaking point but only to delay it (Kranthi et al. 2017; Mohan 2018, 2020; Tabashnik et al. 2021). Bt cotton thus never provided benefits that were "sustainable over time", as proclaimed early on by agro-economists (Sadashivappa and Qaim 2009, p. 172; Krishna and Qaim 2012).



[Publication 2] Figure 10: Model of sociobiological obsolescence of Bt cotton technology in relation to profits

Similar to the corporate strategy of obsolescence, the breaking point of Bt technology has implications for seed producers and adopters alike. Due to its limited life cycle, Bt technology involves a risk for farmers such that they become trapped on a technological treadmill, which causes them to rely on ever-new generations of Bt cotton seeds in response to ever-new resistant pests, with corresponding profits gained by the seed industry (Stone and Flachs 2017). The almost exclusive reliance of Bt cotton in India on hybrid seeds reinforces these effects (Herring 2007; Ramasundaram et al. 2011; Gutierrez et al. 2015; Stone and Flachs 2017; Kranthi and Stone 2020).

By exposing the *sociobiological obsolescence* inherent to Bt technology, we confirm the claim of Taylor (2018) and Nightingale et al. (2020) that technology always needs to be assessed in practice (cf. Glover 2011). The case of Bt cotton in India is exactly one of the "techno-managerialist solutions" that policy makers, planners and the industry still favour (Nightingale et al. 2020, p. 345). These 'solutions', however, remain bound to an imaginary reductionist technological fix that has little to do with the experiences of people and the vibrant ecological reality at local levels. As our case shows, the study of technologies such as Bt cotton is less about the effects of autarkic artefacts but more about the sociobiological dynamics that artefacts spark in society and ecology. Against this backdrop, we view *sociobiological obsolescence* as a promising notion for the assessment and evaluation of future biotechnologies that are currently advertised to tackle the calamities associated with global environmental change.

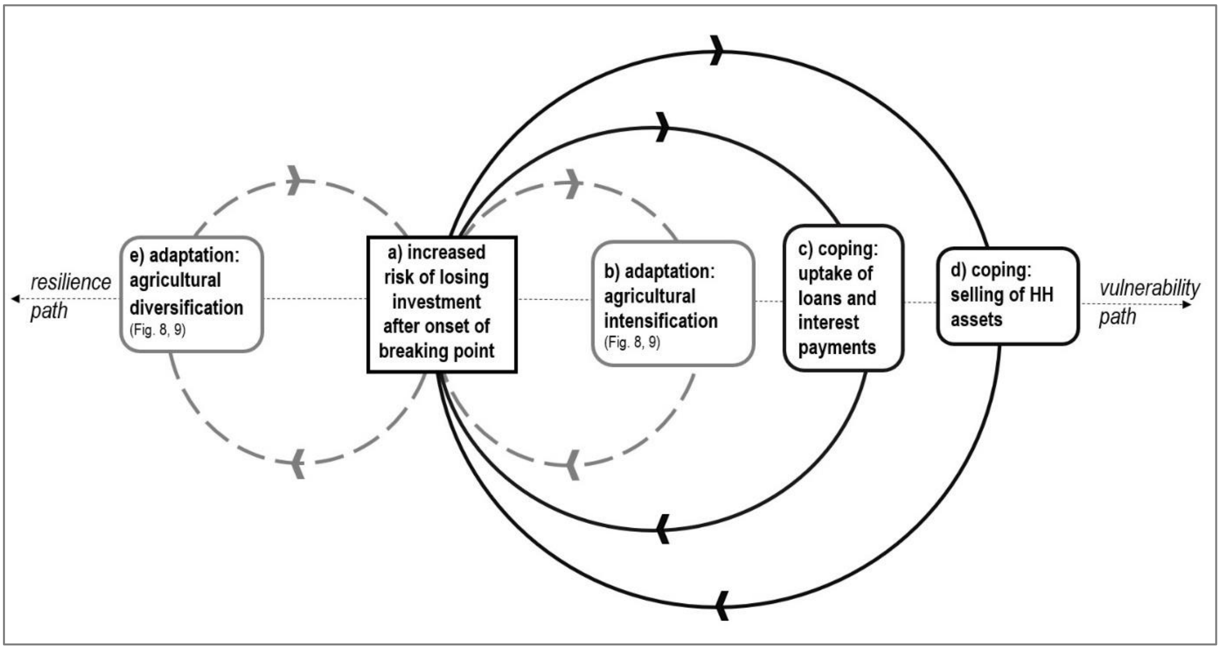
6.6.2 Dispossession and appropriation

Our findings further show that the *sociobiological obsolescence* of the current Bt cotton generation has altered the vulnerability of farming HHs. However, significant differences were found among the interviewed farmers in terms of their economic assets, as resource-poor farmers were especially hit hard by the return of the PBW. We argue that the increased vulnerability of disadvantaged farmers reflects a process of dispossession, which provides economically advantaged actors with opportunities to appropriate HH assets, thus reproducing the existing structures of the emerging neoliberal agri-food regime.

Gutierrez et al. (2015) found that the cultivation of Bt cotton increases the vulnerability of farmers in rainfed areas and argued that this originates from the combination of increased seed costs and continued insecticide costs with low and highly variable yields (Ramasundaram et al. 2007; Glover 2010; Kumar 2015; Matthan 2021). According to Gutierrez et al. (2015) and Gutierrez (2018), the cultivation of Bt cotton involves an increased risk of farmers becoming bankrupt and becoming burdened with debt (Vasavi 2012, 2020; Najork et al. 2021). While our data confirm the findings of these studies (Gutierrez et al. 2015; Gutierrez 2018), our findings also suggest a need to further differentiate among groups of Bt cotton farmers based on their economic situation. This can be shown when loans are considered. In our study, the vast majority of loan recipients had to rely on informal sources, such as landlords or commission agents, due to the restricted access of the otherwise preferred formal banking system to land- or gold-owning HHs (Pal 2002; Altenbuchner et al. 2018; Najork et al. 2021). As these informal sources usually have exorbitant interest rates—Gutierrez et al. (2015, p. 10) describe "usury costs" of 5–10% per month—they involve the danger of farmers becoming trapped in a debt cycle (Vasavi 2014, 2020; Gutierrez 2018; Ramprasad 2019; Najork et al. 2021). Our findings confirm that after having lost their investments in seed, fertilizer, and pesticides due to low or lost yields, some of our interviewed farmers had to repeatedly procure loans, and almost one-third of the already indebted HHs had to take additional loans in subsequent seasons. We therefore agree with Vasavi (2014, p. 33), who reported that “debt and indebtedness generate entrapments”.

Moreover, we argue that the HH strategies follow either a ‘resilience’ or a ‘vulnerability path’ (Fig. 11) in response to the loss of investment after the breaking point (a). On the vulnerability path, this loss can lead to the uptake of loans and the payment of interest (c). If farmers become entrapped in this way and cannot pay back their debts, they are forced to sell their most valuable HH assets, such as gold, equipment, or land (d) (Najork et al. 2021). In summary, these involuntary reactions of farmers to address the Bt technological failure in turn increase the vulnerability of farmers and increase their risk of being faced with a crisis.

As a way to counteract this treadmill effect, our results indicate a resilience path taken by HHs with diversified production (Figs. 8, 9). This adaptation strategy (e), however, is only available to HHs that have the necessary resources. Economically weaker farming HHs were found to be unable to follow this pattern and were left with no alternative but to adhere to intensification practices (b). We found that one potential cause of this was related to the lack of availability and lack of access to sufficient water resources. Gutierrez et al. (2015) emphasized the differences between irrigated and rainfed Bt cotton areas in India and found that farmers in rainfed areas (central and southern India) face higher risks than those in irrigated areas (northern India). With our study, we can show in detail how this plays out in the current situation. As the capabilities of resource-poor farmers to afford adequate irrigation facilities are limited, these farmers are left with no alternative but to apply an increasing amount of pesticides when faced with PBW infestation. This form of agrarian intensification increases their input costs and leaves farmers at an increased risk of losing their investments when yields are not as expected. Thus, the constraints to agricultural diversification faced by resource-poor households are not caused by the increasingly obsolete seed cycles as such. However, the obsolescence described above exacerbates their production constraints by depriving them of further monetary resources that could contribute to more diversified agricultural production (e.g., through the installation of irrigation facilities). Hence, obsolescence-induced dispossession widens the gap between resource-poor and resource-rich HHs, and consequently, resource-poor HHs are further disadvantaged in terms of their adaptive capacities in response to the dispossession caused by *sociobiological obsolescence*.



[Publication 2] Figure 11: Coping and adaptation strategies of farming HHs and the resultant paths of vulnerability or resilience

Farming HH coping strategies (b) and (c) not only produce losers but also winners. As such, there is a counterpart to the story presented above that should not be neglected. Here, our findings are in accordance with those of Jakobsen (2018b, p. 15), who argues that “there are still accumulating classes”, and with those of Lerche (2013, p. 400), who found that there has been no “general pauperization of all agrarian classes” and that “accumulation is disproportionately concentrated in the hands of the best-off groups in the best-off states” (Lerche 2014, p. 51). In our case, the winners are money lenders, often businesspeople, landlords, or large-scale farmers, who earn money from HHs in need by granting them loans and profiting from the associated interest and compound interest (Najork et al. 2021). If farming HHs have to sell their jewellery, the same group of people make gains. Finally, if farmers become unable to repay their debt and interest, the very mechanism described by Harvey (2005) as accumulation by dispossession gains traction; i.e., the farming HHs’ crisis created by the *sociobiological obsolescence* of Bt cotton and intensified by their limited capabilities to cope forces farmers to sell their land—often under value, since the need for financial resources predominates. This freed capital can be easily seized by local elites and those who are better off, thus improving their personal economic situation while contributing to the further increase in farmland-related capital in the hands of a few. Our deductions, thus, highlight that for an analysis of neoliberal agri-food regimes, it is essential to consider perspectives of class and hegemony, as accumulation cycles and class dynamics are coproduced and “class forces in society have been instrumental in consolidating capitalist hegemony in India’s integral state”

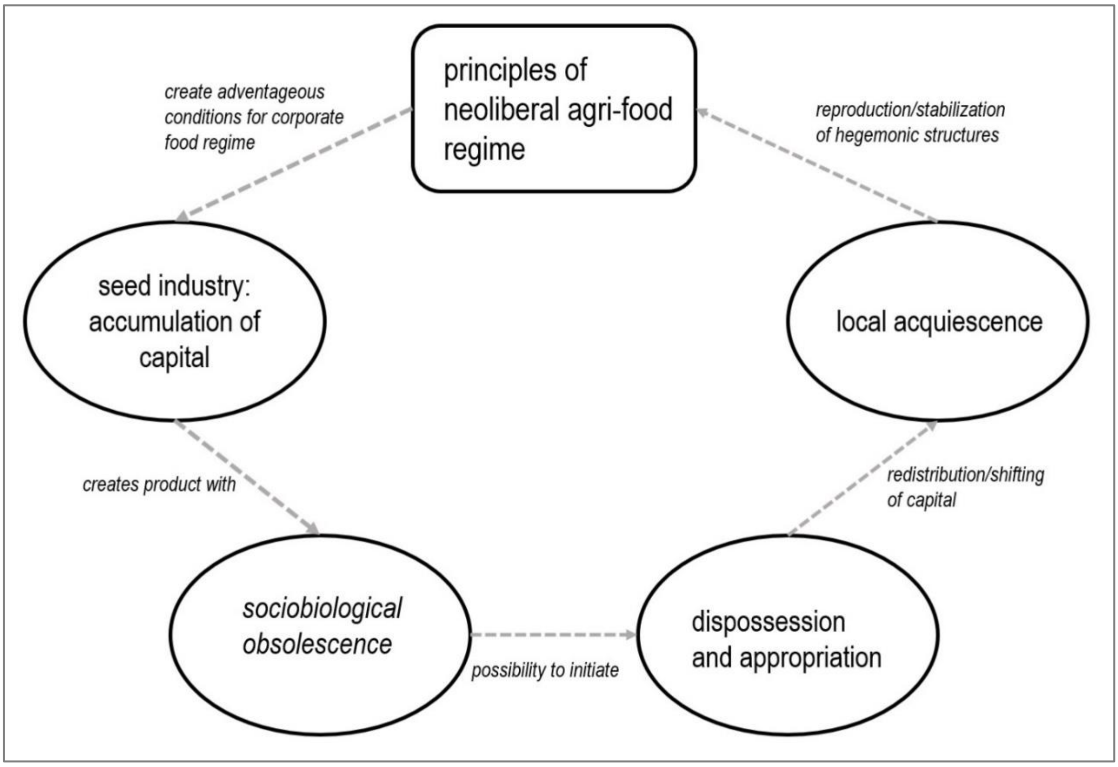
(Jakobsen 2018b, p. 4; Aga 2019). In the following section, this is examined in more detail for our case of Bt cotton in the neoliberal Indian agri-food regime.[37]

6.6.3 Local acquiescence to the neoliberal food regime

In a recent paper, Brown (2019) argues that critical agrarian studies have overemphasized acts of resistance to agri-food regimes and thus sees the need to direct more attention towards the ways in which ordinary populations consent to the formation and stabilization of the emerging neoliberal regime in India (Brown 2019, p. 189). In his view, grand acts of resistance and outright rejection of agri-food regime principles are exceptions, whereas the more 'normal' scenario involves elite dominance and subaltern acceptance (Brown 2019). With the help of a Gramscian understanding of hegemony, Brown aims to highlight how the neoliberal agri-food regime becomes accepted and is conformed to by large parts of society, even if its functioning principles obviously work against them. Gramsci (1971, p. 180f) perceives a vital point in the ruling class to learn to guide the interests of subordinate groups such that they become harmonized with their own interests. As such, he perceives the need to win consent from the larger society with core agri-food regime principles, for which local mediation through a rural elite becomes key (Brown 2019, p. 192). Overall, this act of obtaining consent must be backed by a supportive state apparatus, which provides the necessary modes of governance so that the industry can continue to proceed in a self-serving accumulating regime.

Against this backdrop, we argue that money lenders, shop owners and landlords play—willingly or unwillingly—the role of local mediators. As they gain from the current biotechnology-driven cotton regime by means of earnings in the form of interest payments and the sale of arable land, they have an interest in prolonging and even strengthening this regime's very principles. In doing so, they reproduce the neoliberal agri-food regime in India, which eventually unabatedly contributes to increased accumulation for national and international seed corporations (Fig. 12). Our views are thus in line with those of Jakobsen (2018a), who criticizes the binary agribusiness-versus-smallholder perspective indicated in classic agri-food regime analysis perspectives (McMichael 2009). We see that established powers are favoured, and the underlying processes of accumulation in the current corporate agri-food regime are legitimized and, hence, stabilized through the local acceptance of rural beneficiaries (Jakobsen 2018a, b; Aga 2019; Brown 2019).

[37] With the term agri-food regime, we refer to food regime theory. Food regimes also include non-food crops, as they are concerned with the production and consumption of all agricultural products, such as agrofuels or cotton (Friedman and McMichael 1989; McMichael 2009). In fact, cotton plays a vital role in food regime theorization as the first food regime (1870–1930) described by Friedman and McMichael (1989) is considered to have established a breakthrough in international trade of industrial products, centred on colonial and national relations in which the fibre crop was traded. In an attempt to make this clear, we speak of agri-food regimes instead of food regimes.



[Publication 2] Figure 12: Possible stabilization cycle of neoliberal agri-food regime principles

As a result, we emphasize the role of the classic rural elite, which comprises the actors mentioned above, as they play a key role in making corporate dominance in the Indian agrarian sector more socially acceptable (Jakobsen 2018a, b; Brown 2019). The very nature of the strategies, networks and mechanisms of how this works for our case in practice and how it is interrelated with the wider sociopolitical landscape at the local level remain to be studied in further detail in the future. However, at this point, we can suggest that Bt cotton, and with it other types of similar biotechnology forms, helps the neoliberal agri-food regime take a more mature hegemonic position in India—not due to seed industries that exert coercive means, but by a state-industry complex that provides ground for the rural elite to profit from the current regime, even though this is not the case for all farmers. The long-term consequences of this system are the continuing proletarianization of rural populations along with a further centralization of capital (for example, in the form of farmland and labour supply) in the hands of a few with each new sociobiological failure of Bt technology. We therefore emphasize that Glover (2010) has exposed the falsity of early-on claims classifying Bt cotton as a pro-poor technology (Kathage and Qaim 2012; Subramanian and Qaim 2010). With this contribution, we complement Glover's (2010) argument by providing final evidence on why Bt cotton was never a pro-poor technology to begin with.

6.7 Conclusion

This is the first study to provide insights into the political economy of the altered vulnerability context of farming HHs associated with the recent resistance of the PBW to second-generation Bt cotton (Bollgard II) in Telangana, India. Our study embeds vulnerability-related findings in a larger political-economic context by revealing a technology-driven form of dispossession caused by the *sociobiological obsolescence* of Bt cotton. Thus, as a neoliberal technology, Bt cotton constitutes one of many variegated mechanisms of neoliberalization that must be viewed as yet another form of capitalist appropriation and accumulation in the Global South.

We characterized Bt cotton as a neoliberal technology that includes an inherent *sociobiological obsolescence* that limits the technology's life cycle from the start. As such, Bt cotton has a predetermined breaking point that forces adopters to rely on ever-new generations of Bt seed and, thus, increases the risk of succumbing to 'technology treadmills'. Our findings suggested that this obsolescence results in vulnerability-related inequalities among farmers, depending on their economic status. We argued that resource-poor farmers are unable to follow a path to resilience and are led onto a vulnerability path that eventually results in dispossession. As a counterpart of this dispossession, we identified opportunities for appropriation by economically advantaged actors, such as money lenders, often businesspeople, landlords, or large-scale farmers, to gain from the current biotechnology-driven cotton regime by means of earnings in the form of interest payments and the sale of arable land. Thus, having an interest in maintaining the current principles of the prevalent neoliberal Indian agri-food regime, they reproduce this regime through local acceptance. In this way, by stabilizing the status quo of the underlying processes of the accumulation of capital by national and international seed corporations, they legitimize the current corporate agri-food regime in India. We therefore found the *sociobiological obsolescence* of Bt cotton to favour the established power relations that redirect capital from the bottom to the top at the expense of already financially disadvantaged HHs. This indicates striking parallels with the notion of accumulation by dispossession, as described by Harvey (2005).

Therefore, we conclude that Bt cotton has never been a pro-poor technology, as it continuously exacerbates present disparities with each crisis its failure initiates. Thus, we ask political authorities to counteract these incongruities by implementing protective mechanisms, such as obligatory compensation schemes to be complied with by seed companies. From our point of view, a long-term solution to ever-adapting target pest pressures cannot be found in yet another generation of Bt technology, as its inherent obsolescence causes recurring livelihood insecurities for Bt cotton-farming HHs.

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7 Mistranslating refuge crops: analyzing policy mobilities in the context of Indian Bt cotton production

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Abstract

In light of recent pink bollworm pest infestations in several cotton-producing states in India, farmers of genetically engineered Bt cotton have faced fierce criticism for their noncompliance with the national insect resistance management (IRM) strategy. We argue that this criticism is short-sighted and one-dimensional. Building upon the literature on policy assemblages we show that the implementation of the IRM strategy in India was seriously flawed due to government-induced mistranslations of foreign strategies in the form of policy-diluting alterations. We first show that India's IRM strategy differs substantially from successful strategies pursued in the USA or China. Second, we present results from a representative survey in the state of Telangana (n=457) and show that India's IRM strategy neglects moral economic considerations and entrepreneurial agricultural logic that Indian cotton farmers strive for. We conclude that pink bollworm pest infestations in India are not the fault of farmers, but rather the result of a mismanaged biotechnology project undertaken by the Indian government and its associated responsible ministries.

7.1 Introduction

In the production of genetically engineered Bt cotton (Bt for *Bacillus thuringiensis*), the planting of refuge crops (*refugia*) is the primary insect resistance management (IRM) strategy adopted worldwide to delay the evolution of Lepidopteran insects to become resistant to the toxin produced by the Bt crop; thus, this has become the prevalent policy measure recommended by seed producers and authorities. However, since Lepidopteran (i.e., pink bollworm) pest infestations have recently returned in several cotton-producing states in India, the planting of these refugia has become the ‘Achilles’ heel for Bt cotton’ in the country (Mohan 2018). While the pest had recently been declared eradicated in the USA (USDA 2018; Tabashnik & Carrière 2019) and had been successfully repressed in China (Wan et al. 2017; Tabashnik & Carrière 2019; Wang et al. 2019; Tabashnik et al. 2021), widespread resistance to the Bt cotton target pest has been reported in central and southern Indian cotton-producing states, such as Gujarat, Madhya Pradesh, Maharashtra, Karnataka, Andhra Pradesh, and Telangana (Mohan 2017; Naik et al. 2018; Fand et al. 2019; Najork et al. 2021, 2022). Since the majority of farmers in India do not comply with instructions to grow mandated refuge crops (Mohan 2017; Tabashnik & Carrière 2019), public authorities and industry representatives have blamed farmers for (unknowingly) causing the biotechnology of Bt cotton to fail (ISAAA 2017). In this paper, we argue that blaming farmers for their noncompliance is short-sighted and one-dimensional, as it neglects the moral economic embeddedness of farmers and the responsibility of Indian state authorities embodied by the Department of Biotechnology (DBT) and the Ministry of Environment and Forests (MoEF) as well as associated responsible committees.

We build upon the literature on policy assemblages to show that the implementation of the IRM strategy in India has involved serious mistranslations. The literature concerned with policy assemblages replaces concepts of knowledge transfer and diffusion with the notions of translation and mutation (e.g., Peck & Theodore 2010; Peck 2011). We extend this discussion by focusing on the rural context of India (Keck 2019; Najork et al. 2021, 2022) and show that policy mobilities need to consider local adaptations pursued by actors ‘on the ground’.

In the first step of our analysis, we build upon the approach of “following the policy” (Peck & Theodore 2012; Prince 2017; McCann & Ward 2013) and highlight the contextual twists and turns that IRM regularities have undergone while being adapted to India. In doing so, we show that India’s failed IRM strategy differs substantially from the strategies pursued in the USA and China. As examples of successful policy implementation and pest control, the IRM strategies of the latter two countries, which together with India are the three leading countries in global cotton production, were selected for comparison in this study for two reasons: First, they serve as contrasting counter-images to India’s failed policy implementation. Second, Indian authorities indicated the aim to follow their examples in terms of IRM strategies.

In the second step of our analysis, we move to the site of designated policy implementation by presenting results from a representative survey in the state of Telangana (n=457), including bivariate analyses and a multivariate cluster analysis. In this step, we revert to previously gathered qualitative data to contextualize our quantitative findings in the respective local setting. In this regard, we draw on moral economic considerations, which have hitherto been overseen in the critique formulated by Indian state authorities and industry representatives. We thereby expose the role of the Indian state, embodied by the responsible ministries and committees, in being accountable for involved mistranslations. The overall aim of our study is to explore the information that is being lost in the manifold translation processes inherent in India’s IRM strategy and to challenge the dominant narrative claiming that farmers are responsible for the failure of Bt cotton.

7.2 Policy studies: from policy transfer to policy assemblages, mobilities, and mutations

To disentangle the translation nexus of refuge policies in the context of genetically engineered organisms (GEOs), we revert to the body of literature engaged in *policy assemblages, mobilities, and mutations* (Peck & Theodore 2010; Peck 2011; McCann & Ward 2013; Stone 2012, 2017; Prince 2017), which builds upon and extends the notions of policy transfer and diffusion (e.g., Dobbin et al. 2007).

The concept of *policy transfer and diffusion* is rooted in orthodox political science but is an “intrinsically geographical” approach (Peck 2011: 774). Due to neglecting the variegated social, relational, and territorial contexts of policy activities, the idea of policy transfer has faced increasing criticism (Peck 2011; McCann & Ward 2013; Prince 2017). Critics claim that policy transfer lacks attentiveness to the complexity of policy translation nexuses, as it relies upon the presumption of a linear and straightforward transferability of intact policy models, usually in the form of best practices and direct lesson drawing (Peck & Theodore 2010; Stone 2017). As a result, it fails to consider the relational dynamics of policy making and the possibility of policy modification, transformation or failure (Peck & Theodore 2010; Stone 2012). It is therefore unable to do justice to messy interpretative realities and falls short in terms of addressing political interests or asymmetrical power relations (Peck 2011; Stone 2012).

Inspired by and aiming to address these criticisms, the approach of *policy assemblages, mobilities, and mutations* emerged from the interdisciplinary field of critical policy studies (Prince 2017; Savage 2020). This approach is “attentive to the [constitutive] sociospatial context of policy-making activities” (Peck 2011: 774; Peck & Theodore 2010). It recognizes that policies can hardly be transferred directly and linearly and that policy formation and transformation, being constituted by predominant power relations, must be understood as social, relational, and territorial (Cochrane & Ward 2012). The idea of policy mobility and mutation, rather than transfer, entails the notion of a more dynamic, complex, and power-laden constitution of policy translation processes and networks that “involves a wide range of practices and sites” (McCann & Ward 2013: 9). It is emphasized that policies morph and mutate throughout their journeys and do not arrive as complete packages but instead “move in bits and pieces” and are thus constantly reshaped (Peck & Theodore 2010: 170).

Policy translation therefore encompasses not only a “straightforward copying of policy” but rather entails a broad spectrum of objects and modalities of transfer (Stone 2017: 4). The resulting spectrum of policy adaptation underlines the active construction and reassembly of policies and their implementation through policy actors on a local level (Stone 2017; McCann & Ward 2013). Policies are thus constantly reshaped at the local site of adoption throughout the process of mobilization.

Policies are not only locally shaped but they also shape places in turn. Peck and Theodore (2010: 170) emphasize that “mobile policies, then, are not simply traveling across a landscape – they are remaking this landscape”. The two authors thus argue that “all policies are local” (ibid.). Cochrane and Ward (2012: 4) provide reasoning as to why this ‘localization’ occurs; hence, policies cannot be transferred straight from point a to point b “because they emerged from and are responses to particular ‘local’ sets of social and political conditions which are not replicated in the places to which they are transplanted”.

This post-transfer conceptualization of mobility and mutation has lately been fruitfully stimulated by concepts of policy assemblage that originated from Deleuze and Guattari (1987) and are related to Latour’s (2005) actor-network theory (ANT) (Latour 2005)[38]. The approach views policy translation as an actively constituted rather than statically arranged ensemble. This ensemble is relationally assembled through practices and stresses the perspective of spatiality (McCann & Ward 2013; Prince 2017; Savage 2020). As such, it helps to “think policy mobility beyond the local-global binary” and instead argues that the global and the local are produced in the (policy) assemblage (Prince 2017: 336; Keck 2019). Policy translation is thus understood as a complex social process entailing morphing fragments – not as the transfer of immutable things (McCann & Ward 2013: 8).

In the following, we aim to apply the approach of *policy assemblages, mobilities, and mutations* to the Indian context of Bt cotton refuge policy authorization and implementation. For this endeavor, we ‘follow the policy’ (Peck & Theodore 2012) from the national level of its first authorizing administrations (USA and China) to India. We map out the mutations and mistranslations the policy has undergone in its mobility due to administrative alterations. We then ‘follow the policy’ further to its local sites of implementation on Indian cotton farms by demonstrating that Indian administrative authorities have not sufficiently taken the local realities of Bt cotton farmers into account to successfully put the IRM strategy into practice.

[38] Methodologically, for example, the Latourian ‘follow the thing’ from ANT has been adapted to policy studies in the form of ‘follow the policy’ (Peck & Theodore 2012).

7.3 Following the policy to India

By following the perspective of policy assemblages, we now show that India's IRM strategy differs substantially from the successfully pursued policies in the USA and China, leaving Indian farmers as the only remaining group of actors responsible for repressing the evolution of resistances in the abovementioned pink bollworm population. In the following, we thus briefly sketch the initial refuge policies of the USA and China before outlining the Indian policy adaptations in more detail.

7.3.1 The background of Bt cotton refuge policies

Equipped with genes of the Bt bacterium, Bt cotton produces endotoxins that are lethal to lepidopteran insects and thus creates in-built pest resistance for the Bt crop (Kathage & Qaim 2012; Kaviraju et al. 2018; Naik et al. 2005). Originating from concerns about evolving resistance in lepidopteran insects and therefore aiming to enhance the technology's longevity, IRM strategies were developed by academic, industrial, and regulatory experts[39] (Head & Graham 2012; Tabashnik et al. 2021). In the production of Bt cotton, the planting of refuge crops is the primary IRM strategy adopted worldwide to delay the evolution of insect resistance to the GE crop (Tabashnik et al. 2021; Mohan 2018, 2020; Kranthi et al. 2017). Areas of refuge crops consist of non-Bt cotton plants that are cultivated near the Bt cotton field to allow for the reproduction of the target insects without evolutionary pressure imposed by the Bt toxin (Mohan 2018). Based on population genetic theory, this strategy assumes that inheritance of resistance is recessive; when the Bt-susceptible larvae produced through the refuge mate with the nascent Bt-resistant moths emanating from Bt cotton crops, their offspring should again be susceptible to the endotoxins so that in the end resistance in the insect population to the Bt crop remains neglectable (Gould 2000; Mohan 2018, 2020; Tabashnik et al. 2021).

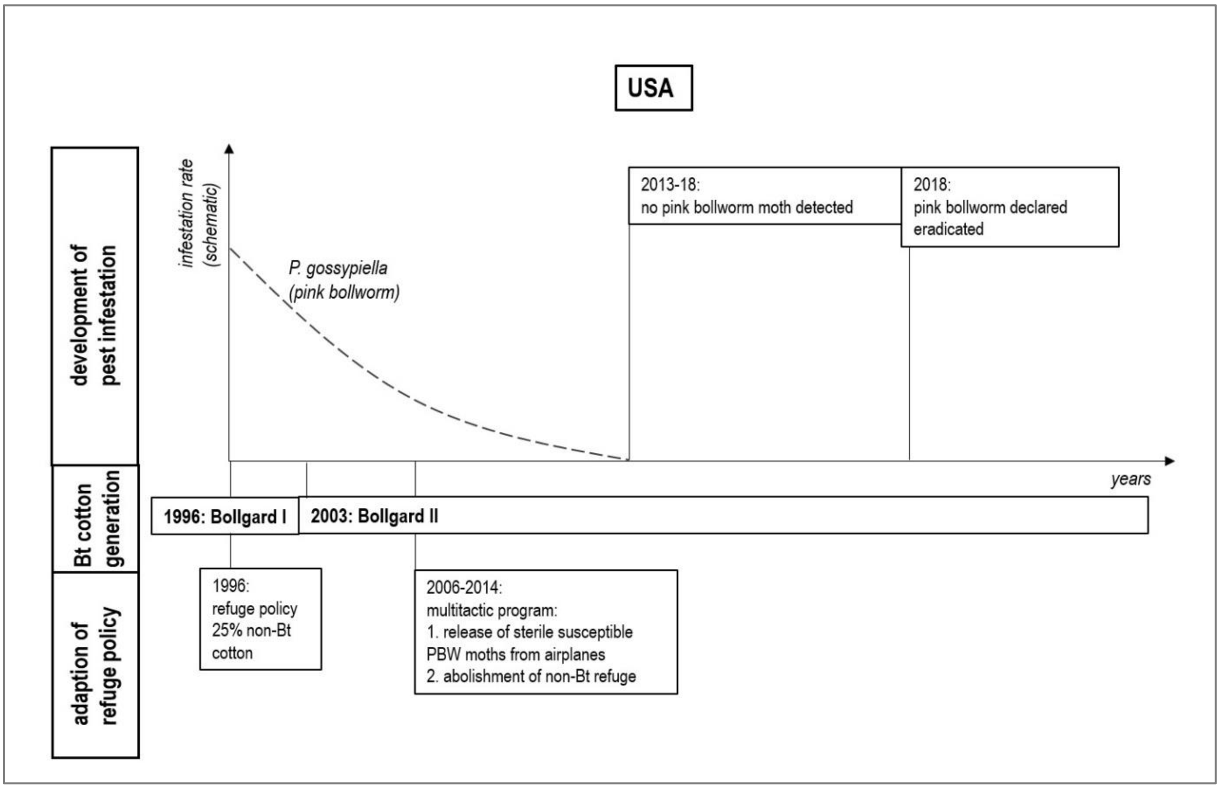
7.3.2 The US refuge policy

Similar to the implementation of Bt cotton itself, the adoption of the concomitant refuge policy was first introduced to the USA in 1996 (Tabashnik et al. 2019). Today, the country is the third-largest producer (after India and China) and the largest exporter of cotton (USDA 2020b). The crop is predominantly grown in the "Cotton Belt" of 17 southern-tiered states, and its production

[39] In this study, we follow the Bt cotton related IRM policy from the national administrative level to the local farm level. We also deem the role of seed producers to be vital in the process of policy crafting. However, as we focus on the national level of policy formulation and the local level of policy implementation, we leave the intermediate level of the seed industry as a promising topic for further research.

in the country is characterized by a high degree of mechanization (USDA 2020b). The average cotton farm size covers 1,312 acres (approx. 530 ha), and average yields amounted to 2,712 kg/ha (seed cotton) in 2019 (FAO 2021; USDA 2007). US cotton farmers are protected through crop insurance and risk-management programs from yield loss (e.g., weather-related) (USDA 2020b).

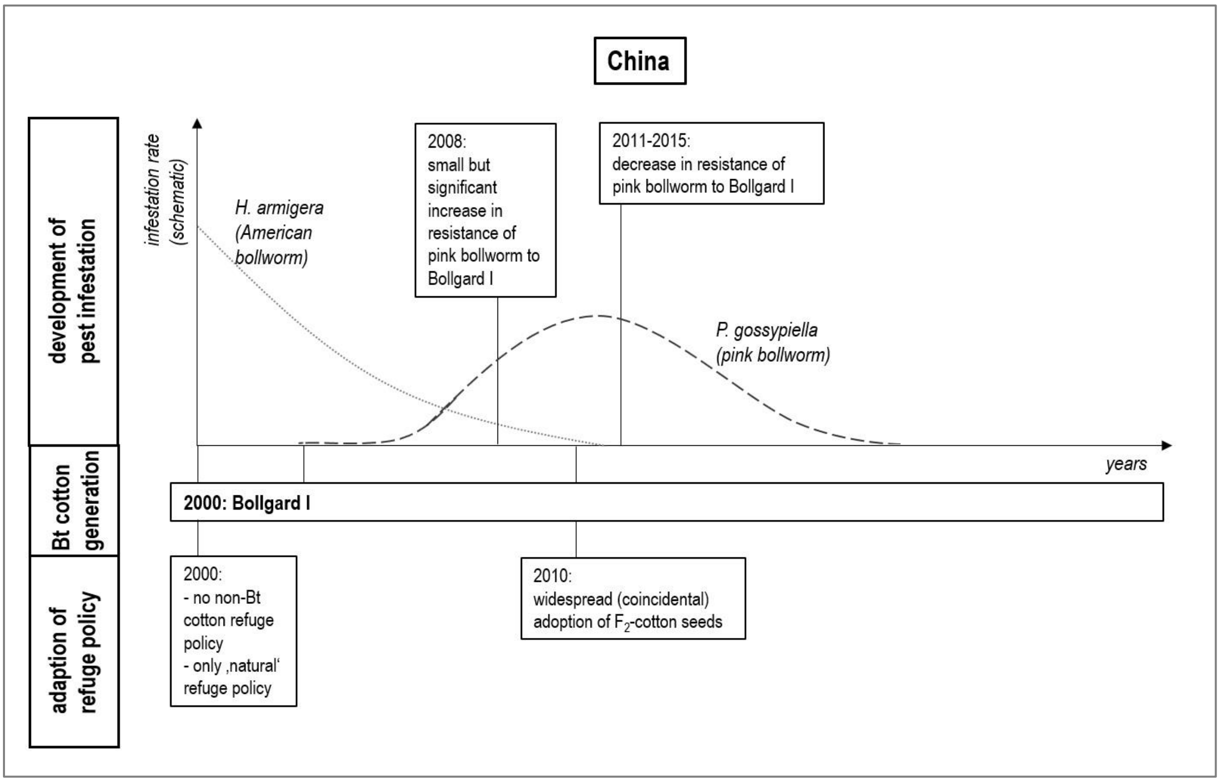
The Bt cotton-related refuge policy was stipulated by the Environmental Protection Agency (EPA) under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) (Frisvold & Reeves 2008). Cotton growers largely complied with the decreed policy that required a non-Bt cotton refuge area of 25%, so from its authorization in 1996 until 2005, >25% of the area planted with cotton was comprised of non-Bt cotton planted in blocks or rows separate from the Bt cotton field (‘structured refuge’) (Tabashnik et al. 2012, 2021). This policy measure was followed by a multitactical collaboration program from 2006 to 2014. This included releases of billions of sterile pink bollworm moths susceptible to the Bt toxin from airplanes in southwestern USA and northern Mexico, which were intended to mate with Bt-resistant moths (Mohan 2018; Mohan & Sadananda 2019; Tabashnik et al. 2010, 2012, 2021; Tabashnik & Carrière 2019). As the remaining progeny were supposed to be exposed to the highest possible dose of Bt toxins, refuge measures were abandoned entirely, thus exclusively leaving Bt cotton expressing the relevant endotoxins (Tabashnik et al. 2021). No pink bollworm moth was detected in US cotton fields from 2013 to 2018; hence, the pest has recently been declared eradicated (USDA 2018; Tabashnik & Carrière 2019) (Fig. 1).



[Publication 3] Figure 1: Refuge policies and pest development in the USA

7.3.3 The Chinese refuge policy

Chinese cotton production is mainly located in the region of Xinjiang and the valley of the Yangtze River, where the crop is grown predominantly by small-scale farmers, with small scale cotton holdings averaging 534-800 m² per farm holder (Stone 2007; Du 2012; Wan et al. 2017; Wang et al. 2019). Despite the low degree of mechanization, Chinese cotton yields of 4,812 kg/ha (seed cotton) in 2019 clearly exceed the world average due to a series of labor- and chemical-intensive farming technologies and cultural practices (Dai & Dong 2014; FAO 2021). Unlike most other countries, China introduced the first generation of Bt cotton in 2000 without mandating a non-Bt cotton refuge and instead merely relied upon 'natural refuges' consisting of noncotton crops such as pigeon peas (Jin et al. 2015; Tabashnik & Carrière 2019; Wan et al. 2017). While this strategy maintained the levels of polyphagous lepidopterans, i.e., pests that are not exclusively feeding on cotton, such as American bollworm (*H. armigera*), low, rising resistance levels were observed for the monophagous pink bollworm, which feeds exclusively on cotton, from 2008 to 2010 (Tabashnik & Carrière 2019; Wan et al. 2017; Wang et al. 2019). However, contrary to the expectations of experts who anticipated further increases in pink bollworm infestation, the respective levels fell again from 2011 to 2015, and resistance was reversed (Tabashnik & Carrière 2019; Wan et al. 2017; Wang et al. 2019). This happened despite the lack of policy regulations for non-Bt cotton refuges, due to refugia being sown inadvertently in noteworthy quantities (ibid.). In particular, small-scale farmers cultivated second-generation (F_2)[40] cotton seeds produced from Bt and non-Bt cotton plants and sold by Chinese private seed corporations at 35% lower prices than their F_1 counterparts[41] for economic reasons (ibid.). This seed mixture resulted in a non-Bt proportion of the area under cotton in China from 12% in 2009 to approximately 25% - 27% in the years from 2011 to 2015 (Wan et al. 2017: 5414; Wang et al. 2019: 528; Tabashnik & Carrière 2019: 2518; Mohan 2020: 1748). As a result, the previously observed increase in PBW resistance declined again due to farmers' planting of F_2 seeds (Tabashnik & Carrière 2019; Wan et al. 2017; Wang et al. 2019) (Fig. 2).



[Publication 3] Figure 2: Refuge policies and pest development in China

[40] Hybrid seed production aims to produce seeds that express a higher vigor (e.g., higher yield or size) than regularly bred seeds due to the "heterosis effect" of hybrid breeding techniques. This effect is achieved by crossing previously inbred parental lines which then generate a filial generation (F_1) which expresses the desired properties. The F_2-generation is the filial generation emerging from the F_1-generation. As the relevant genome decays in the following generations, their properties are considered unreliable.

[41] While the issue of seed purity is also present in India and lively discussed in the literature in the context of stealth and spurious seeds (Herring 2007, 2021; Ramaswami et al. 2012; Stone et al. 2014), the case differs from the second-generation (F_2) cotton seeds in China. As the biological specifics are out of scope in this paper, we refer to Wan et al. 2017, Singh et al. 2016, and Bakhsh et al. 2012 for more detail.

7.3.4 The Indian refuge policy

While India is currently the world's leading cotton producer, Indian cotton production is mostly in the hands of smallholders with average farm sizes of 3.7 acres (approx. 1.5 ha), characterized by a low degree of mechanization (e.g., manual weeding and harvest), and yields below the world average of 1,157 kg/ha (seed cotton) in 2019 (FAO 2021; ISAAA 2017; Kumar et al. 2021; Stone 2007; USDA 2020a). Indian farmers do not benefit from protection schemes such as crop insurance (Kumbamu 2006). Irrigation systems are not ubiquitous, as only the northern states of cotton production, accounting for 35% of cotton production, are predominantly irrigated, while central and southern cotton-producing states are predominantly rainfed (Choudhary & Gaur 2015). While seed producers in other Bt cotton-growing countries usually revert to non-hybrid cotton seed varieties for the implementation of Bt traits, Indian Bt cotton is almost exclusively induced into hybrids (Tabashnik & Carrière 2019).

The first generation of Bt cotton technology (Bollgard I) was introduced to the country in 2002 and contained a single gene (Cry1Ac) of the Bt bacterium. Intended to produce further pest control through an additively inserted gene, its double gene (Cry1Ac and Cry2Ab) successor (Bollgard II) was introduced in 2006, and today, an estimated 95% of the Indian cotton area is cropped with Bollgard II hybrids (ISAAA 2017). Among the three leading cotton-producing countries, India, China, and the USA, India is the only country that has not (yet) authorized a herbicide-tolerant genetically engineered (GE) cotton variant (ISAAA 2017). The third Bollgard generation (Bollgard III), for example, has not (yet) been commercialized in India as it differs from the first two Bt cotton generations in that it not only includes an insect resistance trait but also an induced herbicide tolerance. While the other two countries have authorized other GE herbicide-tolerant cotton variants, this genetic modification hitherto remains unauthorized by the Genetic Engineering Approval Committee (GEAC)[42] (ISAAA 2017). However, illegal cultivation of Bollgard III crop has recently led to a major controversy among cotton farmers and authorities in the country (ISAAA 2017).

In India, the refuge policy measure was introduced parallel to the Bt cotton technology itself when the GEAC under the Ministry of Environment and Forests (MoEF) concurrently stipulated refuge specifications for the crop (Choudhary et al. 2014; Kranthi et al. 2017; Mohan 2018, 2020; Shukla et al. 2018). In contrast to the original policy decreed in the USA, which required a refuge share of 25%, these adapted refuge policy specifications advised that 20% of the total Bt cotton area of a given acreage be cropped with non-Bt cotton hybrids or "a minimum of five border rows of conventional (non-*Bt*) cotton hybrid of the corresponding *Bt*-hybrid" be planted for each field, whichever is higher (Kranthi et al. 2017; Mohan 2018; Kumar et al. 2021). As these guidelines came into force, Bt seed producers were directed to provide a separate

[42] Since 2010 renamed as Genetic Engineering Appraisal Committee.

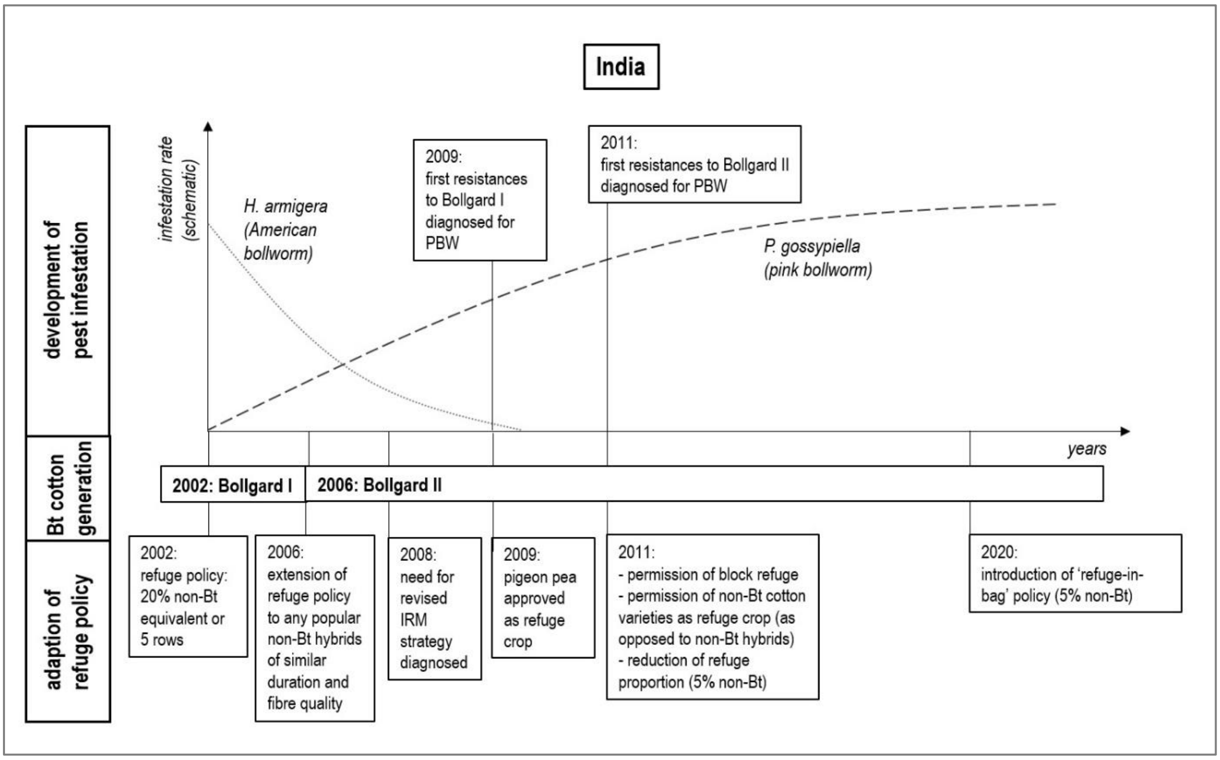
package of non-Bt seeds (120 g) with every package of Bt seeds (450 g) (Fig. 3) (Mohan 2020; Kranthi et al. 2017).

[Publication 3] Figure 3 a) and b): Seed bag with structured non-Bt refuge seeds (Najork 2019)

While this translation of the policy measures had hence remained similar to its original version initially mandated by US authorities, these stipulations were subsequently modified by the GEAC and adapted to the Indian context (Mohan 2020). Mirroring the lack of practical feasibility for seed producers and users alike, due to the great expense of retrieving non-Bt original cultivars from inbred lines of now popular forward breeding techniques[43] (Mohan 2018), in 2006, the GEAC eased the guidelines regarding refugial non-Bt cotton crops so that the required refuge crop characteristics were extended from the isogenic Bt hybrid, i.e., the exact counterpart of the respective hybrid apart from the Bt trait, to any popular non-Bt hybrids that were of similar duration and fiber quality (GEAC 2006). Then, in 2008, the committee diagnosed the "need to suggest [an] alternate and practical IRM strategy suitable for the agricultural practices in the region" due to a low compliance level and thereby stressed the necessity of localized policy adaptations (GEAC 2008). Interestingly, in regard to policy mobility and lesson drawing, the authority directly hinted at the option of taking the successful "experience of US and China […] into consideration while formulating the [revised] IRM strategy" (GEAC 2008). In the following years, the committee authorized several alterations to the policy. In 2009, the committee approved the cultivation of pigeon peas as a refuge crop around Bt cotton fields, arguing to emphasize traditional agricultural practices in the region (GEAC 2009). These noncotton refugia were found to be effective against the major cotton pest prior to the introduction of Bt cotton in India, the polyphagous American bollworm (*Helicoverpa armigera*). However, similar benefits could not be found for the case of the monophagous pink bollworm (*Pectinophora gossypiella*) (Mohan 2018; Sarate et al. 2012).

[43] As opposed to backcrossing breeding techniques which revert to the original cultivar for each individual seed breeding, forward breeding techniques use the most promising cultivar of each seed generation as recurrent parent (Mohan 2018). Forward breeding techniques thus complicate the process of retrieving original cultivars, such as non-Bt cultivars from parental breeding lines.

Multiple further policy changes were put into practice in 2011. The GEAC permitted the planting of block refuge crops as a single patch instead of prescribing an enclosing refugial area, aiming to encourage policy implementation for smaller farms (GEAC 2011). This again underlines the local adaptation of policies, as Indian farmers' landholding sizes are substantially smaller than those of US cotton farmers. Furthermore, in light of the challenges associated with forward breeding, the use of non-Bt cotton varieties with similar fiber properties was allowed in addition to non-Bt hybrid seeds to facilitate the production of an adequate quantity of non-Bt seeds for seed producers (GEAC 2011: 3; Mohan 2018). The same year, the committee approved the downsizing of the required refuge percentage from the initial 20% to a mere 5%, arguing that now Bt II containing two genes (Cry1AC and Cry2Ab) was widely diffused with improved efficacy (GEAC 2011). Moreover, Indian authorities referred to other Bt cotton-producing countries, where the refuge size had also been reduced, or even abolished, as was the case in the USA (GEAC 2011). However, this line of reasoning ignores the fact that the conditions in these countries were entirely different (Fig 4).



[Publication 3] Figure 4: Refuge policies and pest development in India

Thus, while the USA and China were able to prevent the Bt resistance of pink bollworm populations or even eradicate the pest altogether, in India, pink bollworms are now considered resistant to both authorized Bt cotton generations (Bollgard I and II) (Wan et al. 2017; Tabashnik et al. 2012, 2021; Tabashnik & Carrière 2019; Mohan 2018, 2020). In response, the Indian refuge policy has recently undergone another transformation. In 2016, the implementation of 'refuge-in-bag' (RIB)[44] was endorsed and executed in 2020 (Mohan & Sadananda 2019; Kumar et al. 2021). In contrast to the 'structured refuge' policy with RIB, the mandated 5% of non-Bt cotton seeds are integrated in and blended with the Bt seed package (475 g) (Fig. 5) (Kumar et al. 2021; Kranthi et al. 2017). Hence, by withholding farmers from the choice of (refraining from) planting a refuge, this method is referred to as 'compliance-assured' (Mohan 2020; Kranthi et al. 2017). The fact that Indian authorities resort to this technique of enforcing the refuge policy against the policy recipients' consent demonstrates again that the farmer is regarded as the decisive obstructing link in the chain of refuge policy implementation.

[Publication 3] Figure 5: RIB seed package (Najork 2019)

7.3.5 Mistranslations at the national administrative level

Our analysis of the refuge policy assemblage at the national administrative level shows that India's IRM strategy differs substantially from the successful strategy pursued by the USA and the coincidentally effective implementation in China. Whereas in the USA, a multi-tactic strategy was applied, which first followed the strict implementation of refuge crop plantings and then shifted to the dissemination of sterile moths with the concomitant renouncing of refuge crops, Indian authorities relied entirely on refugia as the only IRM strategy while at the same

[44] Sometimes also referred to as 'built-in-refuge' (BIR) (Kumar et al. 2021).

time diluting this monotactic strategy through unilateral policy alterations (Tabashnik et al. 2021; Mohan 2017; USDA 2018). We interpret these policy-diluting alterations as mistranslations. First, they left out entire parts of the policy measures they intended to copy (e.g., the dissemination of sterile moths); second, they adopted other parts of foreign policy alteration while neglecting relevant counterparts (e.g., they reduced the required refuge percentage without complementing the multitactical aspect of the sterile moth releases); and last, they defectively regulated existing policies (e.g., allowing noncotton refuges as an alternative to non-Bt cotton refuges despite the prevalence of monophagous insects). These contrary developments in bollworm populations underline that policy modifications are the result of a complex meshwork (Peck & Theodore 2010; Cochrane & Ward 2012). At the same time, it needs to be acknowledged that the USA portrays a successful example of policy implementation, which involves an immense financial and administrative effort and requires resources that might not be available to other countries. This hints at asymmetrical power relations and the power-laden constitution of policy translation processes (Peck & Theodore 2010; Peck 2011; Stone 2012; McCann & Ward 2013), as pressures of a globalized market can enforce the implementation of progressive technologies in countries that fail to uphold durability in technology due to economic limitations.

At the same time, India did not benefit by chance due to random mutation of the policy's implementation, unlike China, where the coincidentally active role of farmers as well as Chinese seed producers helped to successfully suppress the target pest. In the case of China, it was thus an unintentional mutation of the policy that led to a successful translation by mere chance (Tabashnik & Carrière 2019; Wan et al. 2017; Wang et al. 2019). This shows that policies are embedded in messy realities, and they morph and mutate (Peck & Theodore 2010; Peck 2011; Stone 2012). Thus, special attention should be given to the notions of randomness and arbitrariness when considering policy assemblages.

To solve the problem of an unsuccessful refuge policy translation for Indian authorities, we see the responsible Indian state authorities in compulsion to act, and not, as is often argued, the Bt cotton farmer. While relying on China's successful policy implementation would mean blindly trusting a coincidental policy mutation, we suggest US policy as a potential solution in the form of a state-run multitactical program that includes the release of sterile moths on the one hand and a concomitant renunciation of refuge crop implementation on the other hand. With that, we underline the necessity for Indian authorities to proactively tackle the policy mistranslations that have hitherto occurred.

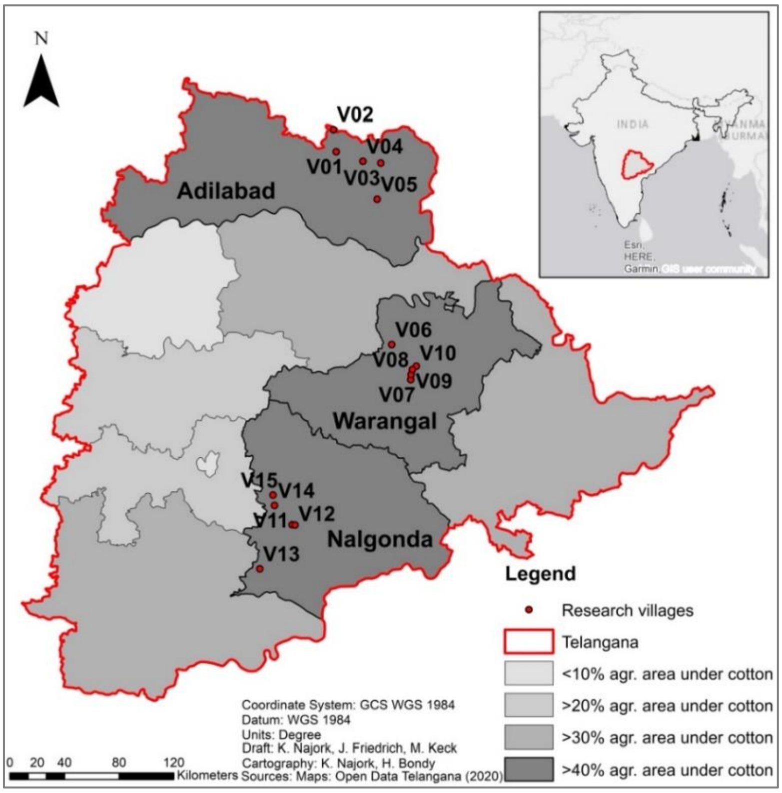
7.4 Following the policy to farmers in Telangana

While the above-outlined adaptations and (mis)translations of IRM strategies depict an international administrative comparison, we now move on to the local level and to the perspectives of farmers. For this purpose, we revert to a mixed method approach, as we present results from a representative survey (n=457) conducted in 2019 in Telangana's major cotton-producing districts Adilabad, Warangal, and Nalgonda (Fig. 6). We later underpin our quantitative findings with previously gathered qualitative data. These data were gathered in Karimnagar district in Telangana in August and September 2018, where we conducted 42 problem-centered interviews in three different locales.[45] The interview partners were mostly Bt cotton farmers but also other relevant actors in the nexus of Bt cotton production.[46]

The districts vary in their geographical characteristics: Adilabad belongs to the northern Telangana zone of agricultural production, Warangal is considered part of the central zone, and Nalgonda belongs to the southern Telangana zone. As such, the precipitation rates of the districts vary. Adilabad ranks highest in this regard with a rate of 1,460 mm in 2018-19, Warangal follows with a precipitation rate of 812 mm in 2018-19, and Nalgonda is the driest of the three districts with 553 mm in 2018-19. For all three districts, the majority of the precipitation occurs during the monsoon (*kharif*) season, i.e., the season during which cotton is grown (from its sowing in June to the harvest from November to January). Considering the population density of the three districts, Adilabad ranks lowest (170 persons/km²), Nalgonda ranks second (245 persons/km²), and Warangal ranks highest (273 persons/km²) (INDIASTAT 2021a, b, c). Warangal's high population density mirrors the supra-regional significance of the district's capital, Warangal city.

Within these three districts, we randomly selected five villages per district within determined *mandals*[47] in the range of 1,000 to 6,000 inhabitants and calculated representative sample sizes according to the Indian Census Data village population size (Government of India 2011)[48]. Interview partners were found via random walks and interviewed by six Telugu-speaking surveyors. Due to our research question, we specifically focused on cotton-growing households. The questionnaire included open-ended and closed questions and Likert-scale, single-choice, and multiple-choice questions.

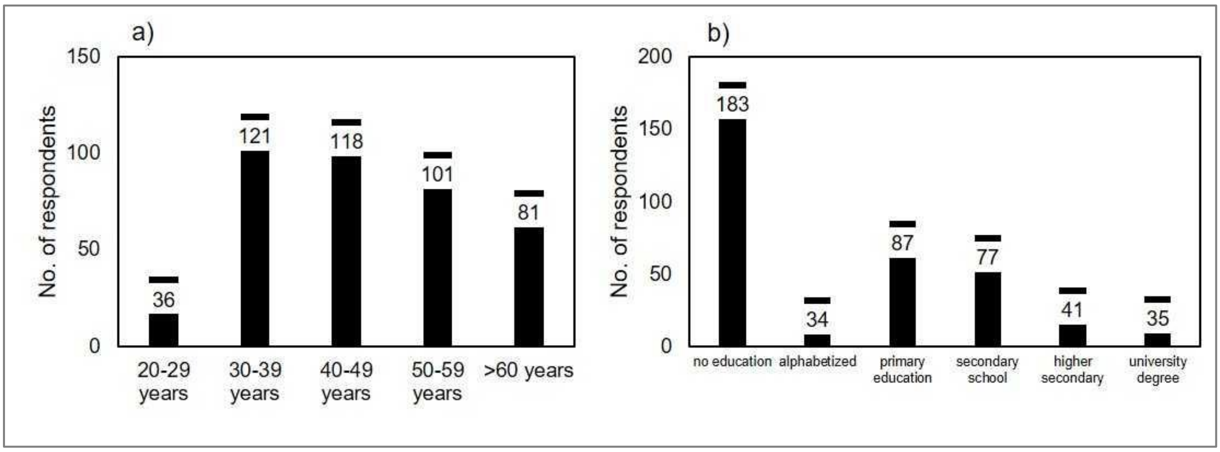
[45] We focus on quantitative data and the conducted cluster analysis for our argumentation and revert to qualitative data only to provide further context for this. Please see (Najork et al. 2021) for a detailed description of the methodology and further empirical insights of the previous qualitative study.
[46] Refer to supplementary information for a detailed overview of the interviews.
[47] A mandal is the administrative division subordinate to a district.
[48] Refer to supplementary information for a detailed overview of the sample.



[Publication 3] Figure 6: Research area in Telangana

7.4.1 General description of the survey sample

The demographics (age) and levels of education of the 457 interviewed household (HH) heads are depicted in Fig. 7. While a majority of the sample (40% or 183 respondents) had not received any education, all categories of education were represented. The distribution of educational levels differed among the three districts (Warangal: 29% with no education; Nalgonda 48%; Adilabad: 49%).



[Publication 3] Figure 7: a) Demographics (age) of household heads (n=457); b) Highest education of household heads (n=457)

The mean farmland size of the interviewed HHs amounted to 5.5 acres (approx. 2.2 ha), with a minimum of 0.5 acres and a maximum of 50 acres (n=456). Of these farms, an average of 4.1 acres were owned, accounting for an average share of owned farmland of 83%, while an average of 17% was leased (n=456). Warangal deviated from the other two districts, with 3.4 acres owned (Adilabad: 4.9 acres; Nalgonda: 4.4 acres). However, the share of owned farmland per household was largest in Warangal, at 88% (Adilabad: 74%; Nalgonda: 81%). The share of owned farmland varied between zero and 100%, indicating large disparities between individual farms. Cotton cultivation took place on 4.0 acres on average, which accounted for 73% of the total cultivated farmland (n=453). The share of land cultivated under cotton was 56% in Warangal but amounted to 77% in Adilabad and 89% in Nalgonda. On an individual scale, the share of farmland under cotton varied between 6% and 100%, resulting in an overall median of 75%.

The vast majority of interviewed HHs (86%) stated that they had grown Bt cotton, and they had been growing Bt cotton for an average of eight years (n=392). The remaining 14% were unaware of their seed varieties (one HH answered that they were growing non-Bt cotton). One percent of interviewed HHs stated that they were growing the herbicide-tolerant third generation (Bollgard III), which is illegal (n=390). Examples of the seed brands used ranged from Nuziveedu (for example, *Bhakti*, *Mallika*) and Rasi (*659*) to Aditya (*Moksha*). Almost all the interviewed farmers (97%) declared purchasing their seeds from local seed shops (n=457). In their seed choice, farmers were mostly influenced by fellow farmers (49%) and shop owners (40%) (n=457). However, the influences varied noticeably at the district level: while in Adilabad, more farmers were oriented toward input shop owners (45%) and less toward fellow farmers (36%), the allocation in Warangal was the opposite (fellow farmers: 54%, input shop owners: 35%; Nalgonda: fellow farmers: 49%, input shop owners: 43%). No farmer responded to be influenced by the governmental agricultural extension services *Krishi Vigyan Kendra* (KVK). The distribution channels chosen for the sale of cotton produce were diverse overall (commission agent: 40%, market auction: 28%, cotton miller 18%, Cotton Corporation of India (CCI): 12%, contract: 2%) (n=457) but varied more at the district level (Nalgonda: commission agent: 64%; Warangal: market auction: 54%; Adilabad: cotton miller: 36%, commission agent: 23%, CCI: 21%, market/auction: 20%).

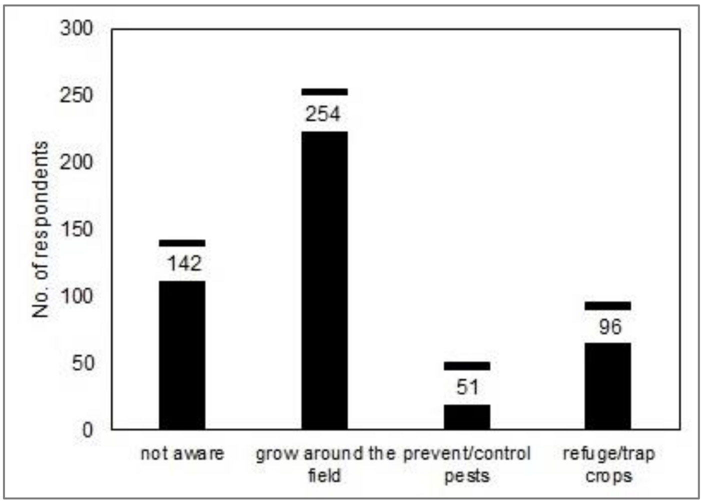
7.4.2 Refuge crop IRM strategy

The subject matter of the refuge crop IRM strategy was examined on two levels, one concerning farmers' theoretical knowledge about the policy and the second its tangible realization in farmers' Bt cotton fields. Regarding theoretical knowledge, 66% of the respondents answered that they had been informed about the Indian refuge policy, and 33%

claimed to have not been informed (n=457). This variable showed moderate correlations with both the educational status of the respondents *(φ=0.246, p=0.000, n=452)*, as those with a higher educational status more often answered to have been informed than others, and their share of farmland under cotton cultivation (*φ=0.263, p=0.000, n=452)*, as particularly those farmers with a share of farmland under cotton of 75% or higher more often answered to have not been informed of the policy. Warangal clearly stands out compared to the other two districts, with 88% of informed respondents (Adilabad: 48%; Nalgonda 52%) (*φ=0.391, p=0.000, n=452)*.

The majority of those farmers who answered that they had been informed about the policy said that they had learned about the policy from the shopkeeper where they had bought their seed (72%) (n=302). Additionally, 10% of the respondents stated that they had been informed by fellow farmers or seed companies, and 8% stated that they had been informed via agricultural officers, advertisements, information on the seed package, or other sources. These figures varied slightly at the district level, exemplified by the percentage of farmers who were informed via a shopkeeper, with 80% in Nalgonda and 64% in Adilabad (Warangal: 71%).

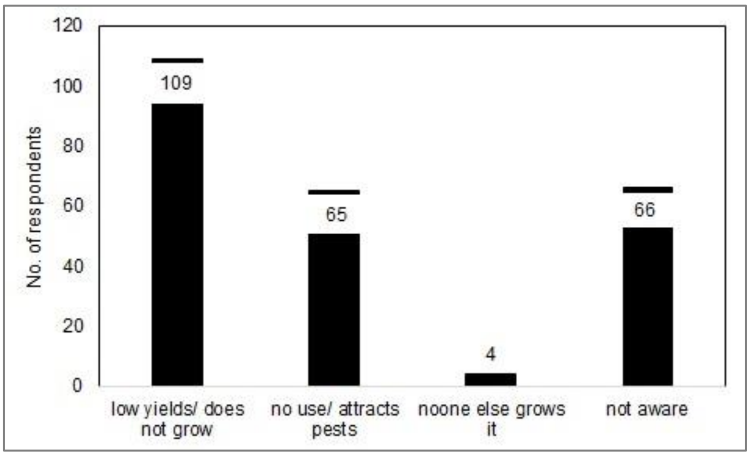
Data relating to farmers' knowledge about the purpose of the attached non-Bt seed package were also collected (n=457). Farmers explained the purpose from their perspective before their answers were inductively categorized. The majority of farmers responded that the crops were to be planted around the Bt cotton field (47%), and 18% were able to give the correct term of the measure ('refuge' or 'trap crops'), while only 9% replied that their purpose was to prevent pest infestation; 26% claimed to be unaware of the purpose of the attached seed package (Fig. 8).



[Publication 3] Figure 8: Suggested purpose of the attached seed package (n=543)

Again, Warangal stands out in a comparison at the district level, as 47% answered that the seeds were to be planted around the Bt cotton field, while in Adilabad and Nalgonda, the majority claimed not to be aware of the purpose (47%; 49%). The concept of mixed RIB was

known by 47%, while 53% were unaware of the new measure (n=457). The concept was noticeably less known in Adilabad (38%) and Nalgonda (25%), but in Warangal, the majority of farmers (72%) knew about the new method[49] (*φ=0.423, p=0.000, n=401)*.
Regarding the actual implementation of the IRM strategy, we found variation among all three districts (n=453). In Nalgonda, only 27% stated to actually grow a refuge; in Warangal, 59% said to do so (Adilabad: 43%) (*φ=0.284, p=0.000, n=453*). The actual compliance correlated moderately with the diversification of cultivated farmland (*φ=0.226, p=0.000, n=453)* and, in turn, with the share of farmland under cotton cultivation, as those respondents with 75% or more of their farmland under cotton answered more often to not be growing a refuge (*φ=0.205, p=0.000, n=453)*. Of those farmers who claimed to grow a refuge, 93% stated that they were growing the required non-Bt crops around their field as opposed to a block refuge on the sides of the field (5%) or the new mixed refuge (2%).
Altogether, 56% of farmers declared that they did not comply with the refuge policy. Of these, 93% stated that they had never done so in general (n=242). Of those farmers who answered that they did not comply, 45% stated that they did not follow the instructions due to “low yields” or because the non-Bt cotton refuge crop “does not grow”, 26% claimed that the measure was “of no use” or even “attracts pests”, and 2% stated not to be growing the refuge because “no one else grows it”. An additional 27% stated that they were not aware of the policy (n=244) (Fig. 9). These particulars varied strongly on a district level (not aware: Warangal: 13%; Adilabad: 26%; Nalgonda: 37%).



[Publication 3] Figure 9: Reasons for noncompliance (n=244)

7.4.3 Cluster analysis

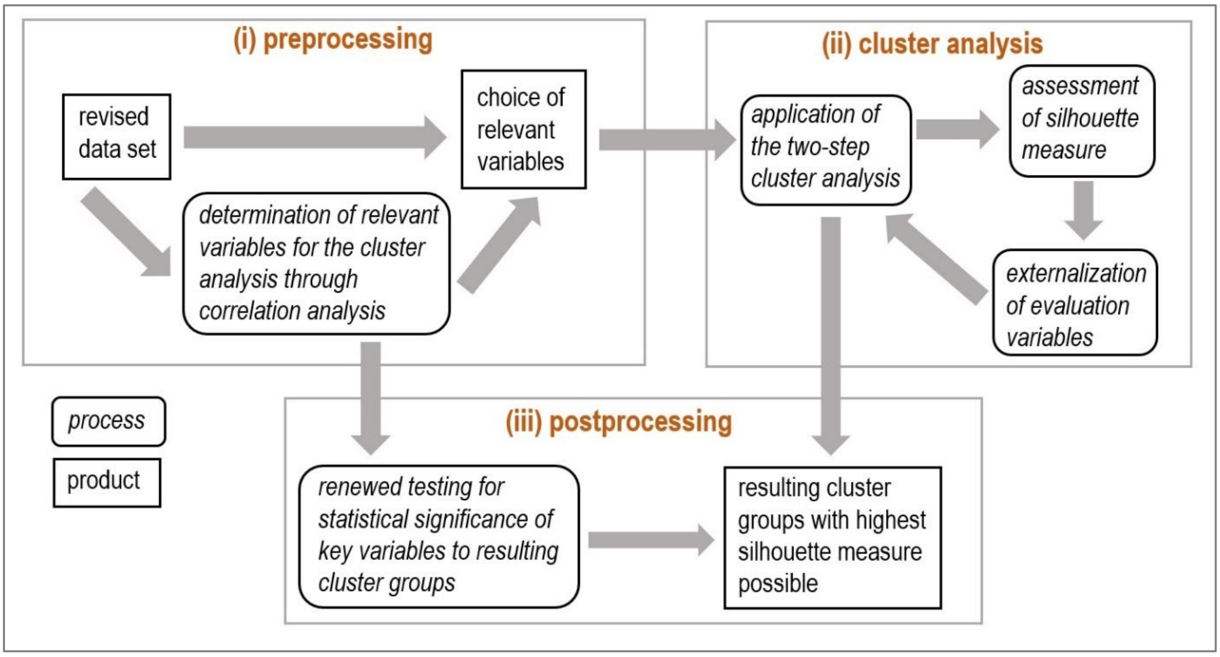
We built on these bivariate analyses for the choice of the most relevant variables for the multivariate cluster analysis (n=438) (Fig. 10 (i) preprocessing). Based on this groundwork, we

[49] At the time of this research in September 2019, the measure of mixed refuge crops was not yet compulsory.

conducted a two-step cluster analysis aimed at identifying different farmer types in the Telangana cotton farming community. While the cluster analysis involved the study of several possible group constellations featuring varying numbers (2-5), we chose the composition with the highest possible silhouette measure (Fig. 10: (ii) cluster analysis). Variables that negatively influenced the silhouette measure were externalized from the cluster analysis itself as evaluation variables. As such, they had no direct influence on the cluster composition but were still examined for correlations. We decided to present a model with two distinguished groups of Bt cotton farmers due to its attributed 'good' cluster quality (average silhouette measure: 0.5). This model comprises (a) 'entrepreneurial' (n=139) and (b) 'diversified' (n=299) farmers. The variables with the highest predictor importance that mostly influenced the categorization of the two clustered groups were those related to farmers' information and knowledge about Bt cotton refuge crops and their purpose (Table 1). The resultant two cluster groups were then again tested for correlations with the original key variables (Fig 10: (iii) postprocessing).

[Publication 3] Table 1: List of key and evaluation variables used in the cluster analysis with summarizing statistics [silhouette measure of cohesion and separation: 0.5; ratio of sizes (largest cluster to smallest cluster): 2.15]

No.	Key Variable	Short name	Scale	Predictor importance
1	informed about refuge crops	REFC_INF_YN	categorical	1.0
2	purpose of refuge crops	REFC_PUR	categorical	0.74
3	currently growing refuge crops	REFC_YN	categorical	0.37
4	level of education	EDU	categorical	0.06
5	percent of cotton in agricultural area	COTTON%	metric	0.01
6	total agricultural area [acres]	FARMLAND	metric	0.01
7	owned agricultural area [acres]	FARM_OWN	metric	0.01
No.	**Evaluation variable**	**Short name**	**Scale**	**Predictor importance**
1	district affiliation	DISTRICTS	categorical	0.14
2	reason for not growing refuge crops	REFC_NO	categorical	0.49
3	degree of severity of lack of irrigation	IRRIG_SE	categorical	0.02
4	degree of severity of drought	DROUG_SE	categorical	0.00
5	degree of severity of pink bollworm infestation	PBW_SE	categorical	0.00
6	informed about refuge crops by seeds shop keeper	INF_SHOPK	categorical	0.98
7	distribution of cotton produce via open auction	DISTRIBUTION_AUCTION	categorical	0.10
8	distribution of cotton produce via commission agent	DISTRIBUTION_CAGENT	categorical	0.05



[Publication 3] Figure 10: Processing the two-step cluster analysis

After processing the cluster analysis, the two resultant groups were again tested for correlations with the key variables and evaluation variables. Significant correlation values that in turn confirmed the results of the previously conducted cluster analysis were found for the variables listed below (Table 2).[50]

[Publication 3] Table 2: Postprocessing correlations

Analyzed variable	**N**	**Pearson χ2 (p)**	**Likelihood ratio (p)**	**Cramer's V**	**V sig. (p)**
REFC_INF_YN	438	0.000	0.000	0.984	0.000
REFC_PUR	438	0.000	0.000	0.859	0.000
REFC_YN	438	0.000	0.000	0.594	0.000
EDU	438	0.000	0.000	0.273	0.000
DISTRICTS	438	0.000	0.000	0.250	0.000
REFC_NO	438	0.000	0.000	0.238	0.000
DISTRIBUTION_AUCTION	438	0.000	0.000	0.294	0.000
DISTRIBUTION_CAGENT	438	0.000	0.000	0.202	0.000
Analyzed variable	**N**	**Pearson χ2 (p)**	**Likelihood ratio (p)**	**Spearman**	**V sig. (p)**
COTTON%	438	0.000	0.000	-0.219	0.000

7.4.3.1 The 'entrepreneurial' group

The first group modeled by means of the analysis accounts for 31.7% (n=139) of the sample (55% from Nalgonda; 29% from Adilabad; 16% from Warangal). In comparison with the second

[50] Those key and evaluation variables that are not listed here either showed no significant correlation values or could not be considered due to low frequency levels in individual cells.

group of farmers, this group is characterized by a poorer layout of socioeconomic resources: Only 17% claimed to have a secondary school certificate or higher, and 57% indicated that they had not received any official education. Their total acreage amounted to $\bar{x}$=5.03 acres, of which $\bar{x}$=4.02 acres were owned.

The two groups differ most strikingly in regard to their knowledge and implementation of the refuge crop policy (Tables 1, 2). This group is defined by the large number of farmers who were not informed about the IRM strategy (100%). Congruously, 90% of the farmers of this group were unaware of the purpose of the attached non-Bt cotton seed package. This was reflected in the high percentage that answered that they did not grow the required refuge (99%). Of the respondents who did not comply with the measure, 48% answered that while not being explicitly informed about the measure, they were aware of it but still did not adhere to it, as its implementation was financially not profitable (unaware: 46%).

The agricultural production of this group is characterized by a specified cotton cultivation, as 81% of their average field area is devoted to cotton; the median of proportional farmland under cotton amounts to 98%; hence, half of the respondents are almost exclusive cotton growers. Due to their pronounced focus on monocropping, which in the production of cotton implies a comparatively high risk (cf. Gaurav & Mishra 2012; Gutierrez et al. 2015), combined with their less detailed knowledge regarding agrarian background information of the crop, we regard this group of farmers as oriented toward short-term profit maximization and refer to them as 'entrepreneurial’ producers.

7.4.3.2 The ‘diversified’ group

This cluster group amounts to 68.3% (n=299) of all interviewed farmers (56% from Warangal; 28% from Nalgonda; 16% from Adilabad). This group is overall better appointed in terms of socioeconomic resources: here, farmers are more educated than the first group, as only 33% claimed that they did not receive any official education, but 39% claimed to have achieved an educational level of secondary school certificate or higher. Additionally, the average total farmland size of this group was slightly higher and amounted to $\bar{x}$=5.72 acres, of which $\bar{x}$=4.09 acres were owned.

In sharp contrast to the first group, 99% of farmers in this group answered that they had been informed about the refuge policy. Of these, 79% received information from their local seed seller, and 95% correctly described the strategy’s purpose as “grow around the Bt cotton field” (50%), “pest control” (16%), or named it accurately as “refuge/trap crops” (29%). Congruously, a higher compliance was found, as only 35% of farmers did not grow the refuge. However, 33% of informed farmers argued that they did not comply because this was financially unprofitable.

Another striking difference from the first group was found in the agricultural production of this group, as it was noticeably more diversified (average of farmland under cotton: 72%; median 67%). Based on this group's diversified cropping patterns and distinct agrarian knowledge, we understand this farmer type to be seeking low-risk and long-term secure production and refer to them as 'diversified'.

7.5 Discussion: Mistranslations at the local level

Given our aim to deconstruct the prevalent narrative that blames farmers' noncompliance for evolved resistances in Indian pink bollworm populations while neglecting responsibilities of the relevant state authorities, we now turn to the local site of Indian Bt cotton production to formulate a critical reading of the current situation. For this endeavor, we interlace our findings with policy assemblages and moral economic considerations.

The moral economy grasps microeconomic practices in situ, assesses the justification and fairness of economic relations and practices in specific localities, and analyzes economic matters on site from a "moral point of view" (Sayer 2018: 4; see also Carrier 2018; Palomera & Vetta 2016; Sayer 2000). While the concept of moral economy dates back to the 18th century, the term was introduced by the historian E. P. Thompson with his 1971 article 'The moral economy of the English crowd in the eighteenth century'. With this essay, Thompson addressed the agency of 'the crowd' by thematizing food riots of the urban working population in 18th-century England (Edelman 2005, 2012; Götz 2015). Later, James Scott (1976) related the concept to rural contexts by linking it to peasant studies with his article 'The moral economy of the peasant', in which he discussed examples of collective action in early-20th-century Southeast Asian peasant rebellions (ibid.). In doing so, he related the micro setting of peasants' everyday life to superordinate structural changes and exposed the entanglements between them, e.g., between farmers' livelihoods, the emergence of colonial states, and the expansion of free trade (Palomera & Vetta 2016). He particularly addressed peasants' subsistence economies and argued that they were carried out by "risk-averse social agents" with a "safety-first principle" as their guiding principle. This stood in contrast to the neoclassical homo oeconomicus or "the would-be Schumpeterian entrepreneur" (Scott 1976: 4, quoted from Palomera & Vetta 2016: 417).

In the case presented here, questions regarding moral economic and refuge policy interlaces concern the role of middlemen (cf. Kumbamu 2006). In line with Kumbamu (2006), our findings confirm that farmers often fall back on middlemen or retailers for advice due to an inadequate influence of extension services (e.g., KVKs). Often farmers rely on the same person for inputs (seeds, pesticides, fertilizer) in the beginning of a season and cash or loans at the end of a (failed) season (V01-I09; cf. Najork et al. 2021). As these intermediaries in turn count on farmers' ability to repay their debt, middlemen have their own short-term economic interests in mind when advising farmers. Unable to refer to the formal bank system for loans (Najork et al. 2021, 2022), resource-poor farmers are particularly dependent on these sources. In this regard, our findings expose geographical congruities, as farmers in Warangal are economically better off on average while less often reverting to commission agents or cotton millers for the distribution of their produce and instead prefer market auctions as their sales channel.

Another moral economic issue that our results expose concerns collaborative long-term consequences in the form of the classical game theoretic prisoner's dilemma (Diekmann 2013). As the testimony of one farmer underscores, the noncompliance is not necessarily due to ignorance: "[S]ince we are not growing a refuge crop, the insects and worms are directly affecting the Bt [crops], and they are becoming resistant to the technology. [I]f everyone start[ed] growing a refuge crop, it would be very useful" (V02-I01). However, despite being aware of the policy, some interviewees still purported that it would simply make no sense to follow the refuge instructions because no one else is growing a refuge (V02-I07; V03-I08). Thus, if they did adhere to the instructions, they would end up with lower earnings compared to those who did not pursue as instructed: "[I]f the neighbor does not grow it, [I] will also not grow it. If I grow it and he doesn't grow it, then he will get more profit than me" (V02-I01). This rationale aligns with the sociological allegory of the prisoner's dilemma, according to which the behavior of individuals can lead to devastating results for the collective (Diekmann 2013). In our case, the entrepreneurial rationale led individual farmers to refrain from compliance while collectively undermining the longevity of Bt technology. Ironically, it is thus the 'entrepreneurial' way of cultivating Bt cotton that thwarts the technology's longevity, as utilitarian monocropping-oriented producers are contributing the least to sustain the long-term efficacy of the technology. Recently, however, as Stone and Flachs (2017) outline, increasingly modern and industrialized cotton production has been promoted in India through Indian government policies, agro-scientific establishment, and favorable market conditions, which has encouraged farmers to turn toward a more entrepreneurial agricultural logic. This mindset of intensifying modernization, incentivized, for example, by climbing support prices of input-heavy cotton, rejects traditional farming practices, as these are regarded as "backward", and instead favors capital- and input-intensive farming practices (e.g., hybrid seeds, increasing water-, fertilizer-, and insecticide-intensity, cash- and monocropping, non-subsistance) (Stone & Flachs 2017; Flachs & Stone 2018). However, in following such "modern" practices, farmers are more susceptible to external influences in their agricultural decision-making (didactic learning), with negative effects on their local knowledge resulting in agricultural deskilling (Stone 2007; Stone & Flachs 2017).

We argue that the above-described administrative mistranslations of the Bt cotton refuge policy at the national level in India result from neglecting this new entrepreneurial farmer subjectivity on part of Indian authorities. We see that certain governmental regulations, e.g., the focus of support prices on input-heavy cotton, incentivize this “modern” farmer type while paradoxically conceiving farmers in general to be still oriented toward subsistence. The relevant Indian state authorities thus ignore the ‘entrepreneurial’ farmer type, aiming at short-term profit maximization through intensified production, which has already been pursued by a large share of Indian cotton farmers. Therefore, we argue that to improve refuge policy translation processes, the responsible state actors cannot merely rely on place-insensitive training programs and educational schemes but need to account for different farmer subjectivities that have emerged in the past decades through the promotion of the logic of entrepreneurial farming practices.

With this argumentation, we add to the findings of Stone and Flachs (2017), who exposed this transition of cotton farmers from traditional subsistence to modernized entrepreneurialism and provided evidence that this shift is accompanied by deskilling and a loss of agricultural knowledge, in our case related to Bt refuge policies (cf. Flachs 2019; Flachs & Stone 2018; Stone 2007; Stone et al. 2014). As our results of bivariate and multivariate analyses indicate, an entrepreneurial agricultural logic, here in the form of an increasing degree of cotton monocropping, negatively impacts the success of refuge policy translations (section 4.3.1).

We see the major cause for this entrepreneurial monocropping strategy to lay in a lack of resources, which drives farmers toward risk taking measures in the hope of gaining short-term profits (cf. Najork et al. 2021, 2022; Louis 2015). Louis (2015) describes this paradox among Telangana cotton farmers, in which the most resource-poor farmers are constrained in their cultivation choice to fluctuating cash-crops like Bt cotton as they simply cannot afford a diversified agricultural production, and are thus pushed toward high-risk cotton monocropping systems for short-term economic benefits[51]. In line with Louis (2015), we argue that these fragile asset-related preconditions pressure farmers to refrain from planting refuges (Najork et al. 2021, 2022; Tabashnik et al. 2010). While sustaining the technology in the long run, refuges go along with yield losses and hence “short-term economic sacrifices for growers” (Wan et al. 2017: 5413; cf. Frisvold & Reeves 2008). Consequently, the cultivation of non-Bt cotton refuges is in direct opposition to the instilled entrepreneurial logic aimed at short-term profit maximization (ibid.). We thus find the origins of the noncompliance at the local level to lie in moral economic questions of its recipients, as is the case for the ‘entrepreneurial’ group of farmers with their restricted asset-related preconditions that is altogether noncomplying. The provision of economic incentives by Indian policy-making authorities to policy-complying

[51] This risk-taking behavior among small scale farmers does not always have a positive outcome, as is shown by alarming numbers of suicides in Warangal and beyond (Gupta 2017; Stone 2011; Vasavi 2009). However, the role of Bt cotton in these farmer suicides remains controversial (Thomas & De Tavernier 2017; Herring 2005).

growers could therefore be a relevant means of achieving local adoption of refuge crops among Indian cotton producers.

This argument aligns with our cluster groups' geographical backgrounds, as the economically better appointed 'diversified' farmers were more often from Warangal, a district that showed both higher averages in owned farmland and a higher degree of agricultural diversification. We therefore argue that here, economically better-off farmers are less constrained in their agricultural production and can afford not to aim only for short-term profit maximization. While the higher average values also apply for the educational level of farmers in Warangal, we do not neglect education as an influential factor. Yet, we want to stress that education is by no means the only influencing factor. As our analysis exposes, the above-described moral economic considerations are of significant relevance and hence must not be neglected when addressing mistranslations in the Indian policy nexus.

However, our findings also reveal noncompliance with the refuge policy for the 'diversified' group. While the majority of this group is informed about and adhering to the policy, again, most noncomplying farmers in this group stated that they would encounter financial disadvantages if they did. We thus found that even parts of the 'diversified' group of cotton farmers have already adopted an entrepreneurial and utilitarian mindset. Consequently, our findings in this regard again underline the significance of moral economic considerations and show that further educating or informing the farming community on the policy does not guarantee a successful translation.

As portrayed by our policy analysis at the local level in connection with moral economic considerations, we found that educational and informational efforts alone cannot counteract the refuge policy mistranslations that have occurred at the national administrative level. Our findings rather show that moral economic issues are key when addressing mistranslations within the Indian refuge policy nexus at the local level. We therefore see the need for economic incentives to be provided by Indian authorities for adhering farmers. Crop insurance or compensation could provide further relief to small-scale farmers and decrease their pressure to adopt short-term economic maximization logics.

7.6 Conclusions

In this article we challenged the prevalent narrative that regards farmers to be responsible for the return of pink bollworms in India's cotton fields due to their noncompliance with the Indian IRM strategy. We therefore followed the policy of refuge crops in Bt cotton production from the national administrative to the local farm level and offered a critical analysis of this narrative informed by the perspective of policy assemblages and moral economic considerations.

On the national level, we showed that India's IRM strategy differs substantially from the successful strategies pursued by the USA and China. For the USA, we found the refuge policy to rest on a multitactical strategy that resulted in the successful eradication of the target pest. For China, we found that a coincidental policy mutation led to the successful suppression of the target pest. In India, in contrast, the policy implementation de facto failed: while being oriented toward successful refuge policy approaches, these were never fully realized. Instead, Indian authorities mistranslated the policy by only partially implementing respective measures while easing or entirely renouncing others.

On the local level, we demonstrated that the farming community in Telangana comprises at least two different farmer subjectivities that are partially pursuing an entrepreneurial agricultural logic. Our findings show that farmers who follow high-risk monocropping and are oriented toward short-term profit maximization tend to not comply with the IRM strategy. Ironically, it is thus this "entrepreneurial farmer", incentivized through favorable market conditions, e.g., climbing support prices of input-heavy cotton, and yet neglected by relevant Indian authorities, who counteracts the technology most vigorously by undermining its potential long-term effectiveness.

Altogether, the analyses of the national administrative and the local level of the policy translation nexus indicate two possible solutions to conquer farmers' noncompliance with refuge crop policies in India – both urging for a pro-active stance of state authorities, not farmers. The policy analysis at the national administrative level exposed a potential solution in the form of a state-run multitactical program that underlines the necessity for Indian authorities to tackle the policy mistranslations that have hitherto occurred on their side by adjusting the unilateral policy alterations they have conducted throughout the policy's adaptation. Additionally, the policy analysis at the local level revealed the relevance of moral economic considerations and speaks for economic incentives to be provided for adhering farmers and for the introduction of crop insurance and compensation payments in case of harvest failures. To date, the responsibilities of Indian authorities have been neglected, and instead, Bt cotton farmers have remained the single entity expected to shoulder the measures necessary for securing the technology's long-term efficacy without receiving financial remuneration. The recent 'refuge-in-bag' variant is now coercing farmers to compliance. We therefore conclude that it is now time for the responsible Indian state authorities to do justice about their mistranslations in regard to the role of refuge crops in cotton production and not, as it is often argued, Bt cotton farmers.

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8 Bioeconomic fiction between narrative dynamics and a fixed imaginary: Evidence from India and Germany

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Abstract

Bioeconomic ideas and visions have received increasing attention from scientists and policy makers to address socioecological challenges. However, the role of imagined futures in the design of bioeconomic innovations and transitions has hitherto been widely neglected. In this study, we therefore explore the role of imaginaries of the future to understand how they shape bioeconomic innovations and transitions. We thereby build on insights from economic sociology and compare two distinct case studies from Germany and India. Based on our results, we inductively develop an analytic model that describes the co-constitution of imaginaries, fictional expectations, narratives, and innovation dynamics. Our results show that narrative dynamics are caused by irritations in the political and discursive landscape; these irritations prompt economic actors to stabilize, adapt, or reject their own bioeconomic conceptions, while the underlying imaginary of a technological fix remains fixed. We discuss this reductionist imaginary and instead plead for an imaginary of a socioecological fix that reintertwines technologies with their underlying societal, cultural, and ecological factors. We conclude that this will support sustainability scholars and policy makers in remaining vigilant against premature mental and institutional lock-ins that could lead to a colonization of the future with severe negative implications for society's ability to mitigate and adapt to global environmental change in the future.

Keywords: Imaginations, Capitalism, Sociotechnical change, Transformation, Future visions, Future studies

8.1 Introduction

In recent years, the notion of a “bioeconomy” or “biobased economy” has become popular among scientists and policy makers as an innovative economic model for addressing the grand societal challenges that accompany global environmental change (Folke et al., 2021; Giampietro and Funtowicz, 2020). Given the wide spectrum of aims and fields of application accompanied by this notion, some authors even propose that the bioeconomy be perceived as a “panacea” by policy makers for obstacles to ultimately reconciling the efforts to meet the Sustainable Development Goals (SDGs) within the limitations of the planet’s life support systems (Giampietro, 2019). As the aim and scope varies, so do definitions of the concept of bioeconomy (Bugge et al., 2016; Hausknost et al., 2017; Vivien et al., 2019). For instance, the European Union (EU) and the organization for Economic Co-operation and Development (OECD) have published bioeconomic strategy papers that have very different goals and include entirely different theoretical approaches. To bring some order to the situation, we refer to Bugge et al. (2016), who identified three major visions of the bioeconomy, namely, the “bio-technology vision”, the “bio-resource vision”, and the “bio-ecology vision”. The “bio-technology vision” aims to create economic growth and jobs through the commercialization of new technologies, while the “bio-resource vision” seeks to combine economic growth and sustainability by converting and upgrading biological resources. The “bio-ecology vision” is ultimately driven by the goal of fostering sustainability, biodiversity, and ecosystem conservation through the development of integrated production systems and high-quality products. According to Hausknost et al. (2017), the “bio-technology vision” emerged first, while the other two visions followed later.[52]

Like other technical and organizational innovations, bioeconomic models are based on specific “imagined futures” (Beckert, 2013, 2018). Imagined futures are basically visions of how the future might look like; they are explicitly or implicitly entailed in scientific studies, reports and strategy papers and help policy makers, producers and consumers develop a more concrete idea of what can be expected or not. The role of imagined futures has thus far been widely neglected in the research on sustainability transitions associated with sociotechnical change (Feola, 2020; Knappe et al., 2019; Longhurst and Chilvers, 2019). Retrospective studies on bioeconomies and sustainability transitions have discussed how the introduction of specific innovations can lead to mental or institutional lock-ins, thus creating path dependencies that are difficult to change afterwards (e.g., Beck et al., 2021; Friedrich et al., 2021a; Graupe, 2020; Trencher et al., 2020; van den Bergh et al., 2015). However, the critical role of imagined futures

[52] Please note that further differentiations of the “bioeconomy” have recently been published by Hausknost et al. (2017) and Vivien et al. (2019). However, in their results, these authors do not differ substantially from Bugge et al. (2016); this is why we rely only on the latter.

in the emergence of new path dependencies and a resultant "colonization of the future" (Beckert, 2018) has yet to be accounted for. With this study, we aim to help resolve this gap.

With a specific focus on the notion of bioeconomy, we provide a comparative analysis of two "diverse" (cf. Seawright and Gerring, 2008) case studies from India and Germany. The first case study offers an example of the "bio-resource vision" of the bioeconomy (Bugge et al., 2016) and discusses innovations that aim to solve the manure surplus and the associated issues of the eutrophication of water bodies and the loss of biodiversity in Germany (Friedrich et al., 2021a). The second case study relates to the "bio-technology vision" of the bioeconomy (Bugge et al., 2016) and discusses the innovation of genetically engineered (GE) cotton that is resistant to Lepidopterans[53]; the aim of this innovation is to increase production while reducing the need for pesticides in India (Najork et al., 2021). While these two case studies might seem unrelated at first, we argue that it is precisely their differences that allow us to identify exploratory commonalities among different imaginaries underlying the bioeconomic sector. Additionally, the two case studies help identify context-related specificities that involved actors pursue to achieve their ends. For this purpose, the concept of imagined futures (Beckert, 2018) provides the theoretical background, while we focus on narratives of economic actors as an analytical category that is empirically accessible and in which imagined futures are becoming visible. By offering an inductively compiled generalizable model of narrative dynamics, we will show how these narratives, which are used to legitimize specific technologies, alter in response to changes in the discursive level of society. With this aim, we will answer the following research questions:

1 What specific narratives do actors develop to effectively present their bioeconomic innovations to the public?

2 How do actors adjust these narratives to changing conditions and discourses?

8.2 Imagined futures and the bioeconomic transition

In this paper, we argue that an analysis of the ongoing transition toward a bioeconomy needs to consider imagined futures, as these constitute the driving force of capitalism in the form of cognitive resources for identifying new opportunities for capital accumulation (Beckert, 2013, 2018). By outlining possible trajectories for future outcomes, imagined futures, together with fictional expectations and interest-driven narratives, help to bridge much of the prevalent

[53] Lepidopteran insects include butterflies and moths. The most damaging pests in the production of cotton are bollworms, including the pink bollworm (*Pectinophora gossypiella*), the American bollworm (*Helicoverpa armigera*), and the spotted bollworm (*Earias vittella*). Bt cotton provides protection against bollworms and other minor Lepidopterans, such as semiloopers, hairy caterpillars, and leaf-eating caterpillars (Fand et al., 2019).

uncertainty in economic decisions and enable relevant actors to navigate in their specific contexts. At the same time, these imaginations of the future shape (bioeconomic) innovation design and guide sociotechnical transitions, thereby causing intended and unintended consequences (Geels, 2020; Jasanoff and Kim, 2009, 2013).

As decision situations in economic contexts in general and in (sociotechnical) innovation processes in particular are fundamentally marked by uncertainty, (Beckert, 2013, 2018) declares imagined futures to be a crucial precondition for innovation processes (see also Beckert and Bronk, 2019). Since the details and events of the future can never be fully anticipated or calculated, Beckert argues that actors build upon fictions about possible future states to draw conclusions in their decision-making processes. These fictions must be rather broad to allow room for maneuvering and creativity but must be “plausible enough that [they] could become true” (Esposito, 2007, p. 13). Fundamentally, imagined futures serve to suspend disbelief and equip economic actors with a perpetual capability to overcome paralysis and act purposefully despite omnipresent uncertainty about future events (Beckert, 2013, p. 226; Beckert and Bronk, 2019, p. 8). By taking the shape of imaginaries of some future state of the world that is cognitively accessible in the present, these fictions motivate actors to develop innovations that, in turn, continually reproduce the capitalist system (Beckert, 2013).

The mental representations of the imagined future states accessible to actors are referred to by (Beckert, 2013, 2018) as “fictional expectations.” These expectations are fictional in the sense that they represent potential future states as if these states were being realized (Beckert and Bronk, 2019). While these expectations differ from literary fiction in their scope and ramifications, these expectations are likewise anchored in specific narratives (Beckert, 2013; Beckert and Bronk, 2019) that render these expectations tangible to initiators and believers alike, structure their expectations, and create incentives for initiators and believers to act purposefully. Fictional expectations published by state agencies, e.g., can thus be read as signals for economic actors; these signals create an atmosphere of security for investments and for research and development activities (cf. Beckert, 2013). Conversely, such fictional expectations, by guiding innovation processes, help create future states that are hitherto only imagined (Jasanoff and Kim, 2009, 2013; Jasanoff, 2015). Therefore, fictional expectations and sociotechnical innovation co-constitute each other – an issue that standard economics has, for a long time, failed to account for (Beckert, 2013; Beckert and Bronk, 2019). Fictional expectations not only accompany the design and diffusion of innovations but also inevitably constitute them by creating the cognitive and imaginative substratum of what could be possible. Conversely, the design of innovations recalibrates fictional expectations in that the resulting new artifacts and knowledge influence the content and shape of fictional expectations. This inevitably also applies to bioeconomic innovations (Bröring et al., 2020; Friedrich et al., 2021a).

Fictional expectations are at the interface of subjective and collective imagination (Beckert, 2018) and are a product of society's imaginaries that have culturally evolved and express normative knowledge of how societies should deal with social or ecological issues (cf. de Witt et al., 2017; Schlaile et al., 2017, 2021). While accounting for imaginaries (as social structures at the discursive level) and fictional expectations (as tacit knowledge at the individual level), we add "narratives" as empirically accessible modalities that occupy a middle ground between the former two. Table 1 defines the three aforementioned notions in detail.

[Publication 4] Table 1: Imagined futures – key terms, definitions and conceptual scales, as defined by Beckert (2018)

Term	Definition	Conceptual Scale
Imaginary	Mental representation of an envisaged (future) state of the world; this representation motivates actors in their decisions and provides them with guidelines for reaching this state	Discursive level
Narrative	Socially shared and empirically accessible stories, theories or forecasts regarding how the present will be transformed into some imagined (future) state	Middle ground between societal discourses and individual expectations
Fictional expectation	Mental representation of imaginaries; this representation is anchored in economic actors and takes a narrative form, such as a story, theory, or forecast	Actor-oriented level

In the following, we provide an analysis of the two bioeconomies mentioned above. While the notions of imagined futures and fictional expectations provide the theoretical background of our study, we direct our empirical focus toward the concrete narratives that exist around innovations helping to solve the manure issue in Germany (Friedrich et al., 2021a) and Lepidopteran infestations in Indian cotton fields (Najork et al., 2021). Our aim is to reconstruct the irritations and subsequent dynamics that these narratives are subject to and to understand how these narratives are stabilized and adjusted by the involved actors. Based on our findings, we aim to obtain a deeper understanding of the nature of the very imagined future in which the bioeconomic model is rooted.

8.3 Methods and research design

To identify the narratives of bioeconomic innovation actors, we chose to compare two contrasting case studies (see Table 2 for a brief overview of the differences) – one investigating manure-based bioeconomic innovations in Germany (see Section 4.1) and the other examining biotechnological innovations involving genetically engineered organisms (GEOs) in India (see Section 4.2). This comparison follows the logic of "diverse cases" according to Seawright and

Gerring (2008); i.e., both cases originate from the same background (i.e., the idea of a bioeconomy) but are based on very different visions (i.e., the “bio-resource vision” and the “bio-technology vision” of the bioeconomy) (Bugge et al., 2016). We would like to mention that diverse cases cannot represent the entire population but can serve to explore or confirm certain aspects of it (Seawright and Gerring, 2008). Our aim was to seek for similar dynamics of narratives among the two case studies that both share despite their content-related differences between these cases (see Section 4.3).

[Publication 4] Table 2: Diverse bioeconomic cases of Germany and India

	A case from Germany (section 4.1)	A case from India (section 4.2)
Topic	The manure surplus, biodiversity loss issues, and manure-based bioeconomic innovations	Agricultural biotechnology, technological failure and political regulation
Bioeconomy vision (Bugge et al., 2016)	“bio-resource vision”	“bio-technology vision”
Geography, socioeconomics, culture	Global North, industrialized agriculture, productive economy, and discourses on ecological sustainability and energy transitions (Beck et al., 2021; Friedrich et al. 2021b)	Global South; high share of subsistence agriculture; discourses on food security, population growth, and poverty reduction (Choudhary et al., 2014; Kathage and Qaim, 2012; Najork et al., 2021)
Bioeconomic policy strategies	Guiding principles: (1) the development of innovations by using biological knowledge and (2) the design of a circular economy (CE) based on natural resources; the aim is to help meet the SDGs (BMEL and BMBF, 2020)	Focus on “efficiency, productivity, safety and cost-effectiveness of agriculture, food and nutritional security; affordable health and wellness, environmental safety; clean energy and biofuel; and bio-manufacturing” (DBT, 2021, p. 7)

8.3.1 Data acquisition

We conducted 26 qualitative, semistructured interviews with actors in Germany and India; 10 of the interviews were chosen as the empirical base for this study. As this paper focuses on the narratives of economic actors, we limited the interview sample to actors who employed such narratives and excluded other actors. The perspectives of opposing interviewees were purposely excluded from the sample.

Table 3 describes the interviewed actors. In the German case, interviews were conducted to examine contrasting framings of the manure issue and imagined solutions thereto. The interviews included those with actors currently designing bioeconomic innovations and actors from civil society or representatives from farmers' associations who may have opposing perspectives on the issue. In this case, we speak of bioeconomic innovation actors, defined as people or institutions currently developing new innovations related to "substitute products," "new processes," "new products," or "new behavior" (cf. Bröring et al., 2020). A total of 12 problem-centered interviews were conducted, six of which were included in this study.

In the Indian case study, the interviews helped to map the present political landscape in regard to GEOs in India and disentangle the manifold networks that shape the ongoing negotiations involved in promoting, directing and constraining specific fictional expectations relating thereto. For this purpose, the stances and arguments of the main political actors (i.e., political parties; farmers' associations; and industrial, business, trade, and environmental associations) were documented. In sum, 14 expert interviews were conducted with entrepreneurs, politicians and activists, four of which were ultimately included in this study.

The interviews were conducted in German (for the German case study) and English (for the Indian case study). The German quotes have thus been translated into English. While the two interview guidelines (see supplementary information) are basically tailored to the specific contexts of each case study (see Sections 4.1 and 4.2), both guidelines share the common focus of bioeconomic innovation, prevalent political discourses on the subject matter, and actors' motivations and expectations in regard to the future of the technologies.

[Publication 4] Table 3: Overview of interviewed actors in the two case studies

IP (interviewed person)	Case study	Actor description
1	Germany	Economic innovation actor, recycling fertilizer
2	Germany	Economic innovation actor, recycling fertilizer
3	Germany	Scientific innovation actor, duckweed cultivation
4	Germany	Scientific innovation actor, recycling fertilizer
5	Germany	Economic innovation actor, recycling fertilizer
6	Germany	Economic innovation actor, transport of manure and fodder
7	India	South Asia Biotechnology Centre (SABC)
8	India	Farmer representing the Consortium of Indian Farmers Associations (CIFA)
9	India	Company representative from Metahelix Life Sciences under the auspices of the Association of Biotechnology Led Enterprises (ABLE)
10	India	Company representative from DuPont under the auspices of the Association of Biotechnology Led Enterprises (ABLE)

8.3.2 Data analysis

All interviews were recorded and fully transcribed. Data processing was performed by using MAXQDA software. The analysis and coding of interviews followed a combined deductive and inductive approach (Kuckartz, 2014). The first two authors of this article coded the material. We derived our deductive categories from theoretical considerations by Beckert (2018) Section 2, who stresses the relevance of uncertainty, fictional expectations, imaginaries, and narratives for economic decision-making that is directed toward the future (e.g., the design of innovations). We furthermore included the stage of the innovation design and diffusion (roughly guided by the multi-level perspective, cf. Geels and Schot, 2007), possible results of innovation (narrative irritation in Section 4)[54], and actors' innovation distribution networks. Through our analysis, we further added inductively gained categories and examined our data for irritations in technological development, diffusion and adoption processes and, finally, discarded the category of distribution networks. We then used open coding to identify, cluster, and structure different narratives (see RQ 1) about how the interview partners present their technologies to the wider public and which societal issues these narratives are semantically linked to. Furthermore, our empirical material allowed us to identify different dynamics of how these narratives were rejected, stabilized or altered in the face of irritations (see RQ 2 and Fig. 1).

8.4 Results

The following two case studies on the surplus of manure in Germany (Section 4.1) and on genetically engineered cotton in India (Section 4.2) show how bioeconomy actors use certain narratives to generate support for their respective innovations. The main emphases of the following sections are both the inductively discovered dynamics of the narratives deployed in the face of irritations and the strategies of the involved actors to stabilize, adapt or reject these narratives (Section 4.3).

8.4.1 Case study 1: manure surplus, biodiversity loss, and bioeconomic Innovations

In various regions in Germany, nitrate concentrations in surface water bodies and groundwater exceed the maximum permissible values set by the European Union (50 mg/l; (BMEL, BMU

[54] We refer to narrative irritations as events or processes that challenge the previously outlined narrative; these events or processes include public discourses, consumer preferences and new scientific results. An exemplary irritation relating to our case studies is the re-occurrence of the target pest (pink bollworm) of the biotechnological innovation (Bt cotton) in our second case. While the new (bio)technology originally promised to defang pests of the bollworm species (Lepidopterans), this narrative is irritated by the pest's renewed occurrence.

2020)). These high figures are largely attributed to manure surpluses resulting from intensive livestock production. In particular, the infiltration of manure-based nitrate from fields into water bodies raises concerns about the eutrophication of water bodies, the loss of biodiversity and the increase in drinking water costs (Umweltbundesamt (UBA) 2019). Approximately 17% of all groundwater assessment sites in Germany register nitrate values above 50 mg/l, while 27% of assessment sites characterized by surrounding agricultural land use register nitrate values that exceed 50 mg/l (BMEL, BMU 2020). Accordingly, Germany is facing lawsuits from the European Union, and fines of 850,000€ per day for exceeding the specified thresholds are currently discussed (Sundermann et al., 2020).

Against this backdrop, new bioeconomic products for manure management are currently being developed (Friedrich et al., 2021a). These innovations include the cultivation of insects on manure (this innovation could provide a protein-based fodder substitute in livestock production (e.g., Čičková et al., 2015)), the cultivation of duckweed on manure (this innovation could be used as a substitute for soy in livestock production (e.g., Stadtlander et al., 2019)), and the recycling of manure by using manure as a mineral fertilizer substitute (this innovation could help compensate for the finiteness of rock phosphate (e.g., Pintucci et al., 2017) and strengthen the already existing reciprocal transport of manure and fodder between different livestock-intensive and arable regions in Germany (e.g., Asai et al., 2018)). All these innovations fall within the “bio-resource vision” of the bioeconomy (Bugge et al., 2016), as these innovations relate to the conversion of matter. The German government supports the development of the abovementioned innovations through its bioeconomic strategy (BMEL and BMBF, 2020).

8.4.1.1 Key narratives and the technological fix imaginary

Based on our interviews, we identified five different narratives that are used by involved actors to legitimize their innovations to the public (see Table 4). All of these narratives rest on the imaginary of a technological fix for the underlying issues attributed to the surplus of manure. These narratives relate to two major fields: ecological sustainability and economic potential. Specifically, these narratives include i) “closing the loop” in a circular economy, ii) spatially decoupling agrifood systems, iii) substituting conventional mineral fertilizer, iv) protecting soils and higher yields, and v) unleashing economic potential through the widespread diffusion of innovation (see Table 4). i) The circular economy narrative relates to using technology to close (currently open) regional cycles of matter: “It would be much easier to significantly increase the degree of self-sufficiency […] and then, ideally through a circular economy. […] I imagine that I will be able to spread the liquid manure on the field or bring the liquid manure […] to the duckweed.

There are also other ways in which I can increase this circular effect" (IP 3). ii) The narrative of spatially decoupling agrifood systems relates to the end of the area-bound application of manure in livestock-producing regions. Supporters argue that this decoupling will not lead to an intensification of livestock farming: "This means that our concept is a decoupling of areas. This will not lead to an expansion of factory farming because this is no longer possible under current construction laws. […] This means that we can support small and medium-sized farms. We can maintain the basic agricultural structure. […] Yes, let me put it this way: we are back to where we were 150 years ago" (IP 5). iii) The narrative of substituting conventional mineral fertilizer relates to the finiteness of rock phosphate, which can be overcome by using recycled manure instead: "Phosphate is a finite raw material, which we are already seeing today or have seen in recent years, and we are having increasing difficulties processing this raw material because of the many, many impurities. So, the question is, where else can I obtain this raw material?" (IP 1). Relatedly, manure-based fertilizer would also render the energy-intensive Haber-Bosch[55] process unnecessary: "Especially now, from the point of view of CO_2 reduction, we have, for example, been able to recycle nitrogen instead of spending three liters of heating oil per kilogram on transposing nitrogen from the air by using the Haber-Bosch process […] or to completely prevent methanization on agricultural land, including of nitrous oxide" (IP 5). iv) The narrative of protecting soils is related to the use of recycled fertilizer as a carbon carrier that will lead to improved soil health and higher yields: "At the end of the day, we have highly enriched nutrients and carbon carriers. This is one of the issues that is currently being completely overlooked in fertilizer policy, in my view. […] There is actually the issue that they completely neglect the carbon cycle that such soil needs. But it's always just about nutrients and stuff like that. […] You can see that quite clearly in our region. […] The soil structure is gradually changing. […] You can really see this in the yields" (IP 2). v) The narrative of unleashing economic potential through the widespread diffusion of innovations distantly relates to unburdening farmers from the need to pay to dispose of their manure surpluses due to existing legal standards: "So of course it's economically driven" (IP 4).

We categorize all five narratives as relating to a technological fix for the aforementioned manure issue. However, we do so with varying foci based on the different conceptualizations of what is regarded as the actual problem. The first and second narratives address technological fixes for environmental issues, particularly in regard to disturbed biochemical cycles of nutrients; these issues ought to be solved through technological progress. The third narrative also involves the imaginary of a technological fix for environmental issues; however, in this narrative, the environmental issues are specifically related to the energy-intensive production of mineral fertilizer. The fourth narrative concerns a technological fix for

[55] Haber-Bosch process refers to the synthetization of ammonia out of the atmosphere.

environmental and economic issues by arguing for both protecting soil by recycling fertilizer and generating higher yields through more productive agriculture. The fifth narrative ultimately relates to a technological fix for the economic standstill in agriculture; this standstill can be overcome by unleashing the economic potential of manure conversion.

[Publication 4] Table 4: Overview of the imaginaries and narratives of innovation actors relevant to manure-based bioeconomic technologies in Germany

	IP 1	IP 2	IP 3	IP 4	IP 5	IP 6
Type of actor	Company, recycling background	Company, agricultural background	Science	Science	Company. agricultural background	Company, agricultural background
Type of innovation	Recycling fertilizer	Recycling fertilizer	Duckweed cultivation	Recycling fertilizer	Recycling fertilizer	Transporting manure
State of innovation	Development	Development	Development	Finished development	Market entry	Used in market
Imaginaries	Technological fix related to ecological sustainability	Technological fix related to ecological sustainability and economic potential	Technological fix related to ecological sustainability	Technological fix related to ecological sustainability	Technological fix related to ecological sustainability	Technological fix related to ecological sustainability
Narratives	i) closing loops, ii) spatial decoupling	iii) substitution of conventional fertilizer, iv) soil protection and higher yields	i) closing loops	i) closing loops, v) economic potential	i) closing loops, ii) spatial decoupling, iii) substitution of conventional fertilizer	Problem is solved by transporting manure

8.4.1.2 Narrative dynamics

As outlined above (see Table 4), all of these manure-based innovations are in different stages of development. Since the innovations from IPs 5 and 6 are already available in the market, these innovations can be used to show the narrative dynamics involved (for more types of narrative dynamics, see Sections 4.2 and 4.3). We found that both actors use different mechanisms to reproduce and stabilize their narratives over time to be competitive in the market.

IP 5 provides us with two mechanisms that reproduce the narrative (prior to potential irritations), namely, telling economic success stories and building rhetoric coalitions; both mechanisms help the actor address the superiority of the innovation. The success story unfolds as follows: “One of the secrets of our incredible success that we have now [is to] always calculate the quality of the products and whether these can be immediately implemented in the market because we reproduce industrial products one to one as recycled products. That is the crucial difference, and with it, we have completely captured the entire market because all the others have always gone down this traditional path, typically engineering, but just never released any products of value and then just never achieved sufficient profitability” (IP 5). Building rhetoric coalitions is similarly straightforward: “According to experts from universities and chambers of agriculture/ministries with whom we work very closely, we are now highly recommended. They also highly recommend us because they say, ‘This is the best solution that is currently available in the market and it truly works.’ That is the decisive point” (IP 5).

IP 6 provides us with a stabilizing mechanism. The actor argues that the reciprocal transport of manure and fodder between regions characterized by intensive livestock production and arable regions allows the manure issue to be solved regionally while meeting the standards of the German nitrate directive. The actor (who developed the innovation of reciprocal transport of manure and fodder) builds on past experiences of success following the nitrate directive to legitimize his or her own innovation and regards the appearance of new innovations as an irritation of his or her own narrative of having solved the manure issue (for more information on irritation, see Section 4.3); IP 6 indicates this view of new innovations as an irritation by devaluing the company’s competitors. In response to the question, “So, you are saying that these big industrial manure processing plants [the competitors] are not doing what they should be doing, and they are solving a problem that does not even exist in the end?” (Interviewer) IP 6 said the following: “Right. Which now no longer exists. That would have been a sensible thing to do 15 years ago because the whole logistics chain had not yet been set up. Now it has been built up; now many other biogas plants have been built up and constructed with it, and then you take the basis away from them again, just to operate a large system. That is quite wrong” (IP 6). We see this answer as a way of stabilizing IP 6′s own narrative. As such, the planned building of biogas plants translates into an irritation for IP 6 by undermining the favored narrative and elaborated innovation (Fig. 1).

8.4.2 Case study 2: agricultural biotechnology, technological failure, and political regulation

Biotechnology is meant to contribute to a “knowledge and innovation driven Bioeconomy,” and its significance as a “tool for national development and well-being of society” is enshrined in the future vision of India's National Biotechnology Development Strategy (Department of Biotechnology, 2021, p. 1). According to the Department of Biotechnology's recently published strategy documents, efforts are being made to "create a strong enabling environment to promote the growth of the [biotechnology] sector" (Department of Biotechnology, 2021, p. 1); this is a perspective that corresponds to the "bio-technology vision" of bioeconomy (Bugge et al., 2016).

Among the multitude of GE crops researched and developed in India[56], Bacillus Thuringiensis (Bt) cotton is particularly relevant for our study. Bt crops produce Bt bacterium endotoxins that are lethal to key insects, such as Lepidopterans, which are considered a crucial limiting factor in both cotton and eggplant production (Choudhary et al., 2014; Kathage and Qaim, 2012; Kaviraju et al., 2018). As the first and still only authorized GE crop in the country, Bt cotton (Bollgard I) was introduced to India in 2002, while Bollgard I's successor (Bollgard II) followed in 2006 and is currently used on 94% of the Indian cotton area (Choudhary and Gaur, 2015; International Service for the Acquisition of Agri-Biotech Applications, 2017). While never fully accepted, Bt cotton technology was considered by many to be a silver bullet in the fight against bollworms (Choudhary et al., 2014; Kathage and Qaim, 2012). However, the pink bollworm (PBW), the major cotton pest that Bt cotton technology was intended to control, has recently developed resistance to the crop in several Indian states, thus causing plummeting yields and negative socioeconomic effects for farming households (Fand et al., 2019; Mohan Komarlingam, 2020; Naik et al., 2018; Najork et al., 2021; Tabashnik and Carrière, 2019; Tabashnik et al., 2021). The recently developed resistance of PBWs to Bt cotton has been perceived as a major irritation among related innovation actors and has substantially affected the corresponding narratives.

8.4.2.1 Key narratives and the technological fix imaginary

Broadly speaking, all interviewed actors and representatives considered the application of biotechnology in Indian agricultural production to be necessary. Expressed by all four interviewed actors, the superordinate imaginary related to the agricultural biotechnology sector construed biotechnology as a technological fix (IPs 7–10). This imaginary was expressed in the form of various narratives that can be categorized as social benefits, economic potential, and ecological sustainability (IPs 7–10). Specifically, we identified narratives related to i) increased farmer income, ii) workload reduction, and iii) food security in the social benefits dimension; iv) increased yields and v) international competitiveness in the economic potential dimension; and vi) pesticide reduction, and vii) adaptation to climate change in the ecological sustainability dimension (see Table 5).

[56] For an overview, see Choudhary et al. (2014).

In regard to the social benefits dimension of the involved narratives, all interviewees emphasized the importance of biotechnological innovations for farmers. This emphasis was exemplified by IP 7, who described his interest in research as follows: “As an agricultural scientist, I strongly believe that the technology and seed is very crucial for my farmers in India” (IP 7). In this context, the narrative of i) increased farmer income was particularly relevant: “And there, technology has a huge role, particularly in increasing incomes” (IP 9; see also IP 10). One interviewee even voiced this expectation aloud, stating that the goal was “doubling farmer income” (IP 7). Moreover, the narrative of ii) workload reduction was mentioned in regard to farmer well-being: “In the villages, it is very, very difficult for them, too. Physical work is [difficult]” (IP 8). Another important aspect related to the social benefits dimension of the technological fix was that of iii) food security (IPs 7–8). The interviewees expected food security to be jeopardized if the use of biotechnology in agriculture was reduced: “Can we stop 10% of cultivation every year? […] What will happen to national food security?” (IP 8); another interviewee stressed the significance of biotechnology for food security against the background of India’s population size: “Sooner or later, the government has to look at technology. There’s no way that we can run away from development. […] With the kind of population that we have, I think food security is much [more] critical for my country than any other country in the world” (IP 7).

These social benefits depend on narratives related to the economic potential of biotechnology regarding iv) increased yields, as noted by one interviewee: “Our cotton production at the national level actually increased by a factor of three. […] So, I need to look at yield parameters” (IP 7). Another respondent underlined the economic role of biotechnology in India’s v) international competitiveness; the respondent argued that productivity had improved in “every parameter” and hence “India was the largest importer of cotton, [and is] today […] the largest exporter of cotton” (IP 9; see also IP 7; IP 10).

Furthermore, a technological fix regarding ecological sustainability was expected (IPs 7–9). Here, the main point was vi) pesticide reduction, which is of particular interest to actors working with food crops, such as Bt brinjal[57], as voiced by one respondent: “But in India we have half a million brinjal farmers. […] They’re still spraying four or five dozen pesticides to get the brinjal crop out to the market; [this] would be about a barrel pesticide residue inside [the crop], which no one wants” (IP 7). Another respondent even specified the potential future trajectory of possible pesticide reductions: “I would consider probably in the next, maybe, 50 years, if genetic technology is adopted, probably the use of pesticides, insecticides and weedicides will come down, maybe 70, 80%” (IP 8). In addition to the expected reduction in pesticide use, positive contributions regarding vii) adaptation to climate change were mentioned: “Water

[57] Bt brinjal was developed in India from 2005 onward. However, this crop was put on hold after a moratorium was imposed on the commercialization of the crop by the then environment minister in 2010.

shortages, climate change. All this is going to come in, so you have to modify the crops to suit these conditions" (IP 8). The potential of agricultural biotechnology as one of several solutions was thus emphasized: "Yes, GM crops are not a silver bullet; it is one […] of the potent options for addressing the issues that the agrarian scenario in the country faces. Whether it be challenges from climate change [… or the] equitable distribution of development in our country" (IP 9).

[Publication 4] Table 5: Overview of the imaginaries and narratives of innovation actors relevant to GEOs in India

	IP 7	**IP 8**	**IP 9**	**IP 10**
Type of actor	SABC South Asia Biotechnology Centre	CIFA Consortium of Indian Farmers Associations	ABLE (Metahelix Life Sciences) Association of Biotechnology Led Enterprises	ABLE (Du Pont) Association of Biotechnology Led Enterprises
Type of innovation	GE crops (Bt cotton, Bt brinjal)			
State of innovation	Bt cotton: widely used in the market; adoption rate of 94% (ISAAA 2019: 2) Bt brinjal: moratorium since 2010			
Imaginaries	Technological fix related to social benefits, economic potential and environmental sustainability	Technological fix related to social benefits, economic potential and environmental sustainability	Technological fix related to economic potential and environmental sustainability	Technological fix related to social benefits and economic potential
Narratives	i) increased farmer income ii) food security iv) increased yields v) international competitiveness vi) pesticide reduction	ii) workload reduction iii) food security vi) pesticide reduction	i) increased farmer income iv) increased yields v) international competitiveness vii) adaptation to climate change	i) increased farmer income v) international competitiveness

8.4.2.2 Narrative dynamics

The aforementioned narratives have encountered irritations, which were found to play a central role in the narrative dynamics, as these irritations ultimately initiated the rejection, stabilization or adaptation of the original narratives. In the Indian case, technological and political irritations were relevant.

Our results show that the sector recently faced technological irritations caused by the failure of Bt technology and the reoccurrence of pest infestations. The PBW's evolving resistance to Bt cotton's built-in pest resistance – originally the crop's raison d'être – forced the actors involved to adapt their narratives. We found that this adaptation involved a rejection and the subsequent adjustment of the original narratives. As an empirical example, PBW infestation has been belittled and reframed as a mere management problem, and the relation of the problem to Bt technology is negated: "We believe that scientifically, it is very easy to manage pink bollworm […] But I don't think pink bollworm per se would have to do anything with Bt technology. […] I think it's a management practice, and I'm sure that by next season we should be able to contain this pink bollworm problem" (IP 7). While the severe damage caused by PBW infestation was originally the main argument for implementing the technology, this narrative is now rejected due to the pest's evolved resistance. Instead, technology failure is reinterpreted as a narrative of technology application failure.

Another rejected and then adapted narrative concerning this technological irritation is that the technology is said to be advanced, and new technological improvements need to be continually authorized for the technology's benefits to be fully realized: "You don't have to use [pink bollworm resistance] to beat down the technology. Technology development is a continuous process. From the very advent of agriculture, things have been moving. Resistant varieties develop, they succumb, then you have a new wave of varieties, […] so it is a continuous process" (IP 9). While the first generation of Bt cotton was originally presented as a silver bullet in the fight against the target pest, now, after the crop's failure, this narrative is being rejected and adapted to a narrative of constant technological development. This narrative adaptation not only explains the failure of the first Bt generation, thereby stabilizing the narrative of its successful implementation, but simultaneously justifies its successors being repeatedly authorized and implemented. Similarly, one interviewee argued that the yield increase, which he had earlier attributed to the introduction of Bt technology, recently stabilized only because new technologies have not been authorized: "The yields have stabilized because Bt is not a yield technology. […] Bt does not increase the yield per se. […] The yield is stabilized only because then new genetics have to come on top of it" (IP 10).

Our results also revealed the possibility of a stabilization of narratives following irritations. For this stabilization, the interview partners referred to past technological innovation successes before the irritation to further consolidate the technological fix imaginary. As Bt technology has now been used in India for almost 20 years, the respondents could draw on their past experiences related to implementing and diffusing biotechnological innovations. Here, the respondents notably referred to past narratives of success while neglecting those of apparent failures: “Why are [the farmers] cultivating this? Obviously, they see the benefit in this, and the downsides, there are relatively fewer” (IP 9). In this regard, the high diffusion and implementation rate of Bt cotton (94%) throughout cotton-growing areas in India (International Service for the Acquisition of Agri-Biotech Applications 2019, p. 2) was of particular relevance, as it was argued that this high rate had been achieved because of farmers’ preference for the technology: “And today, it is 12 million hectares. And seven million farmers. And who am I to tell my farmers what to do, what not to do? They do it because they like it. They found it to be useful. So, why would I convince my farmers not to use it? […] But I would ask Vandana [Shiva] only one question: Why are there seven million farmers [using it]?” (IP 8). Finally, it was stated that if farmers were unsatisfied, the rates of adoption would have already declined: “they can always discontinue [using it] if it is not working” (IP 7).

Apart from the return of the PBW, political irritations were also mentioned; these included mainly the moratorium imposed on the commercialization of the first GE food crop, named Bt brinjal by the then environment minister, Jairam Ramesh, in 2010 (IP 7; IPs 9–10). One interviewee described the impact of the resulting uncertainties for the biotechnology sector as follows: “In India, I can tell you, until today, we have not been able to do anything because of the moratorium on Bt brinjal. [The] scientific community [is] completely demoralized. Nothing is moving. There is no investment, big investment in this technology. And all that you see today is actually the result of the moratorium” (IP 7; see also IP 9). Thus, “the industry investment in biotechnology [has taken a hit]” (IP 10) due to the moratorium, as was stressed repeatedly (see also IPs 7–9). This description of the demoralization of the entire industry and the lack of investment following the incident shows that the sector’s fictional expectations were shaken, and hence no reliable mental representation of the future remained to direct action or investments toward.

All respondents mentioned path dependencies arising from such political decisions (IPs 7–10), as exemplified by the following statements: “I would say that this was the beginning of the slide of the biotech industry in India. Had Bt brinjal [been] commercialized, things would have been much, much better” (IP 10), and “had he [the former Environment Minister] approved Bt brinjal […] you would have seen very different advancement in technology today in India than what we have now. […] You see, since the moratorium began, […] most of the companies withdrew or downsized their R&D facilities in India” (IP 7).

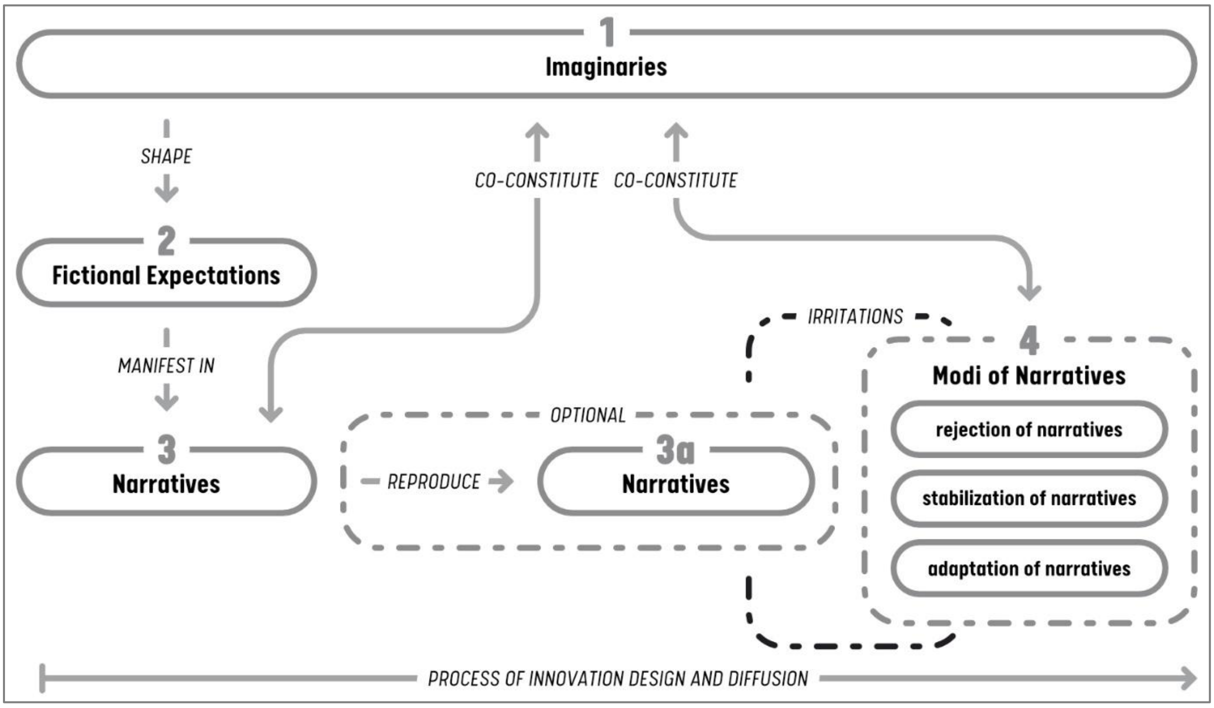
Another political irritation that emerged was the planned governmental price control of Bt cotton seeds: “So, those decisions [about Bt cotton price control] have had further effects. […] Until [the] end of 2015, the industry was suffering because of the unpredictable scenario” (IP 10). As emphasized by all interviewees, these politically induced planning uncertainties had far-reaching effects on research and development (R&D) investments, as these investments, of course, would have to be made before the given innovation could be introduced (IPs 7–10): “For technology development, it’s not like you can just come out with a white paper with some point and say that ‘here is the technology.’ […] It takes time, it takes resources, it takes manpower, it takes intelligence. You need to hire people, […] you need to fill laboratories. And you are liable to the legal structure that you have in the country” (IP 7; see also IPs 8–10). This quote underlines the severity of the irritation after investments have been made.

Ultimately, neither technological nor political irritations prompted a readjustment of the technological fix imaginary. In fact, rather than causing the reevaluation of stakeholders’ elementary imaginaries, the irritations were found to have produced narrative dynamics, as they led to the rejection, adaptation or stabilization of the original narratives (see Fig. 1). The stability of the prevailing technological fix imaginary is emphasized by the interviewees’ indication of the lack of alternatives to biotechnological solutions in agriculture (IPs 7–10): “Yeah, so I’m one-hundred percent sure that, you know, except for technology, there’s no other alternative” (IP 7). In this context, one respondent was hopeful that GE technology “may get delayed, but it will not get denied, because people need it” (IP 9). Thus, in contrast to the dynamic narratives, the original technological fix imaginary remained intact as irritations arose; the imaginary even outlasted the resulting uncertainties.

8.4.3 Synthesizing the case studies: a model of narrative dynamics

Based on our empirical material from the two case studies that present different visions of the bioeconomy (cf. Bugge et al., 2016) in different local contexts, we now develop a generalizable model, depicted in Fig. 1, that describes the co-constitution of imaginaries, fictional expectations, narratives, and innovation dynamics (this builds up on Section 2; see also Beckert, 2018; Geels, 2020; Jasanoff and Kim, 2009). This model illustrates the contrast of fixed superordinate imaginaries and dynamic narratives by showing how narratives are stabilized, rejected or adapted in response to irritations (Fig. 1 [4]). In the following, we outline this contrast on the basis of our case studies. An overview of the narratives and imaginaries presented by the two cases is described in Tables 4 and 5.

As our studies show, the narratives enable economic actors to legitimize their technological innovations vis-à-vis the wider public. In this regard, we discovered different dynamics of change in these narratives throughout the innovation design and diffusion.[58] We found that the narrative dynamics were triggered by irritations produced by internal and external incidents or developments that called respective innovations into question. In the German case, the appearance of new technologies that threaten the success of already existing technologies is one such irritation. In the Indian case study, the technological failure of Bt cotton associated with the return of PBWs and the political moratorium on Bt brinjal epitomized these irritative events. We identified three modes of narrative dynamics that actors implement to cope with such irritations: rejection of narratives, stabilization of narratives, and adaptation of narratives (Fig. 1 [4]). These dynamics can occur in combined or consecutive forms and are not mutually exclusive. In the following, these dynamics are mapped out in detail. We further found that before irritations, actors use similar strategies which we interpret as a reproduction of their narratives serving to support the same (Fig. 1 [3a]).



[Publication 4] Figure 1: Bioeconomic innovations and involved narrative dynamics

An example of the reproduction process (Fig. 1 [3a]) is the building of rhetoric coalitions, i.e., referring to experts to provide narratives with an additional degree of credibility. In the German case (see Section 4.1), interviewees referred to scientific experts to amplify their narrative of the success of a specific technology.

[58] It is beyond the scope of this article to deeply interrogate the different processes involved in the design and diffusion of innovations across time and space. We point to the substantial body of literature in sociotechnical transition studies that covers these dynamics. In particular, we highlight the research on the multi-level perspective and subsequent related research, such as that on different transition pathways by Geels and Schot (2007), who describe different pathways of sociotechnical change.

The stabilization of narratives (Fig. 1 [4]) occurs if economic actors underpin their own narratives with additional information or try to discredit other narratives to make their own more reliable and persuasive. For example, interviewees argue that the high implementation rate of Bt cotton in India (see Section 4.2) can be seen as proof of the technology's success despite the irritation caused by the return of PBWs.

A rejection of narratives (Fig. 1 [4]) takes place if economic actors discard a specific narrative that they had formerly used to legitimize their technological innovation. In this case, these actors turned to adapted or completely different narratives, which may have existed before the irritation or may be created anew. For example, the failure of Bt cotton and the evolving resistance of the target pest forced the relevant actors to drop their original narrative of the first generation of Bt cotton technology being a cure for the PBW problem and instead reinterpret the situation as one of continuous technological development (see Section 4.2).

The adaptation of narratives (Fig. 1 [4]) means that involved actors add or remove specific aspects of the story and change the way they legitimize their technological innovation. This dynamic is found in the Indian case (see Section 4.2), where the failure of the Bt cotton technology forced involved actors to argue that the return of the pest was a mere management problem not attributable to the technology as such.

In addition to revealing these narrative dynamics, the two case studies bring to the fore a single superordinate imaginary that stays unchanged over time, and that is one of a technological fix (for further discussion on this aspect, see Section 5.2). Notably, this imaginary is not shaken, even in situations marked by severe internal (e.g., technological) or external (e.g., political or economic) irritations (see Section 4.2.2). Rather than revising their entire imaginary and thereby questioning their internalized logics, the interviewees adapted or rejected isolated narratives and adjusted them to avoid criticism to ultimately maintain their belief in technology.

8.5 Discussion

In this article, we investigated different narratives that bioeconomy actors used to legitimize certain technologies and examined how these narratives relate to changing conditions and discourses. We applied the economic sociology of (Beckert, 2013, 2018) to bioeconomies and showed that interview partners in both case studies followed the imaginary of a "technological fix" to solve social, environmental or economic challenges (see also Birch et al., 2010; Birch, 2019). The "technological fix" imaginary itself remained static over time as a prevailing idea of progress and development (cf. Harvey, 2003, 2007; Markusson et al., 2017) despite the occurrence of manifold irritations. Our results therefore reveal a sharp contrast to the more dynamic narratives used by bioeconomic innovation actors to legitimize their technologies (see Fig. 1). These narrative dynamics allow the relevant actors to avoid the dismissal of their single superordinate imaginary. Our inductively received model of narrative dynamics (Fig. 1) contributes to the existing theory of imagined futures in that the model describes these futures (in the form of empirically accessible narratives) on the micro level, thereby contributing to the overarching topic of normative dimensions of sustainability transformations (e.g., Schlaile et al., 2017). In the following, we first discuss these results in relation to the duality of the fixed imaginary of a technological fix and the dynamic narratives, and we come up with a plea for escaping fixed imaginaries in an attempt to "decolonize" the future through integrated systems thinking.

8.5.1 Narrative dynamics and a fixed imaginary

The results of our case studies show that the narratives of bioeconomic actors are related to the specific problems and societal discourses in each country. Thus, the technological fix imaginary is realized in different forms and manifestations (see Section 4.1 and Section 4.2). In the German case, technology was meant to solve environmental issues and create economic potential. This was described by using narratives of closing loops, decoupling, using substitutes for the energy-intensive production of fertilizer, increasing yields, and promoting the economic potential of cost avoidance for those willing to adopt the innovation. Socioeconomic narratives appeared to be less relevant than in the Indian case. In fact, in the latter, socioeconomic narratives were found to rather co-constitute the technological fix imaginary, e.g., in narratives of food security, increased yields and income, and the reduction of farmers' workload, while in Germany, public discourses are centered on questions of ecologic sustainability, especially in relation to energy transitions (Beck et al., 2021; Friedrich et al., 2021b); in India, emphasis is placed on how to erase food insecurity and end poverty (Beck et al., 2021; Choudhary et al., 2014; Kathage and Qaim, 2012).
However, although the focus of the narratives differs, our results show that the imaginary of a technological fix underlies all mentioned narratives. While this imaginary stays unchallenged over time, the narratives are dynamically used to defend the idea of a technological fix against all odds (see Section 4.3 and Fig. 1). As the imaginary of a technological fix forms the basic roots of neoliberalism (Harvey, 2003, 2005, 2007; Markusson et al., 2017; McLaren and Markusson, 2020), its fixation has historically grown and is meanwhile deeply inscribed in society (e.g., Nightingale et al., 2020). It is therefore little wonder that this imaginary is highly resilient, thus posing ever more difficulties for any attempt to change it. The narrative dynamics discussed here both constitute and are constituted by the technological fix imaginaries, as these dynamics continually feed the imaginaries with new ideas and argumentations regarding how to effectively legitimize the respective technological innovation. Likewise, the fixed

imaginary continually yields new adapted narratives and relativizes failing innovations caused by external factors.

8.5.2 Overcoming the imaginary of a technological fix: toward integrated systems thinking

In the neoliberal order, problems of public concern are often recast as nonpolitical issues to be solved by technological solutions instead of through changes in socioeconomic relations or culture (Roy, 2011; Scott, 2011); this has been described as technological fetishism (cf. Harvey, 2003). Morozov (2013) extends this by adding “solutionism,” which refers to technological design and innovation that aims to solve problems whose complexity is not fully understood. We argue that similar tendencies apply to our case studies, as bioeconomic technologies attempt to solve highly complex social and environmental problems reductionistically by excluding societal aspects, such as human decision making, thereby possibly overlooking unintended side effects, which are difficult to solve once a certain development path has been taken (see also Friedrich et al., 2021a).

Escaping the imaginary of technological fixes is thus difficult, as it is rooted deeply in neoliberal ideas of growth and development and helps reproduce the neoliberal order (Birch et al., 2010; Birch, 2019). However, what can then be done to potentially overcome this imaginary? In our view, we first need to acknowledge the role of imaginaries in principle, as without them, society would be unable to make new social or technological developments (Ziegler, 2019). Castoriadis (1990) argues that imaginaries, specifically social imaginaries, constitute society as such through shared understandings and meanings; therefore, without social imaginaries, social life would simply be impossible. Thus, imaginaries that materialize in new technologies should not be viewed as negative per se. However, what is needed is an imaginary that is characterized by its own limitations. We can think of a technological fix of a technological issue; but as shown in our study, it is reductionist and may even be risky to rely entirely on a technological fix of societal issues by neglecting the underlying social, cultural and ecological aspects that produce these issues. Against this background, what is needed to grasp the complexity of socioecological problems is to develop an imaginary of a socioecological fix, meaning an imaginary that reintertwines the aforementioned idea of a technological fix with its underlying societal, cultural, and ecological factors. This also means attending to the complexity of wicked problems (in contrast to the “simple” narrative of neoliberalism; cf. Waddock, 2021). We therefore want to stress scientific concepts that indicate possible ways for future thinking. These approaches include, among others, philosophical debates on the ethics of invention (e.g., Jasanoff, 2016), responsible research and innovation (e.g., Owen et al., 2012), dedicated innovation systems (e.g., Schlaile et al., 2017), and adaptive governance methods (e.g., Cleaver and Whaley, 2018; Kovacic and Di Felice, 2019; Bohle et al., 2009). These concepts can help develop short-term strategies for adaptive and dynamic sociotechnological development. We therefore see the necessity of developing these approaches further in exchange with and for society.

As a long-term solution, we argue that societies need open discursive spaces that allow for societal exchange and debate, thereby building the ground for developing new imaginaries that can materialize in or produce new social and/or technological innovations. In our view, transdisciplinary science projects (e.g., Zscheischler and Rogga, 2015) that acknowledge the complexity of problems and the uncertainty of the future and include a broad range of stakeholders, thus coproducing knowledge and being able to influence the imaginaries of society and science, can provide such discursive spaces. Therefore, these projects provide opportunities to discuss wishes, expectations, and, thus, imaginaries of desirable futures (see, e.g., Pereira et al., 2018). In the words of Beck et al., p. 149), this would also mean "attend[ing] better to diversities of visions, actors and commitments that are present when one looks beyond dominant reductive and linear framings. Doing this reduces the risk that visions of transformative change close down, rather than expand, the range of pathways and the diversity of actors and their visions contributing to them." A practical example of how such discursive spaces in society could look like, very close to the transformation toward a bioeconomy, has been demonstrated by Kimpeler et al. (2018), who discussed different bioeconomic scenarios (imagined futures) during participatory workshops with interested societal actors. The results of the workshops show the importance of engaging with society in discussing (desirable) imagined futures, as this acknowledges the diversity of perspectives and knowledge in creating a sustainable bioeconomy. However, in our view, this could even be extended toward open imaginative and discursive spaces (following the idea of transdisciplinary science) that would not just discuss existing ideas (and scenarios) but rather would aim toward creating entirely new imaginaries with society and for society.

8.5.3 Limitations of the research: reflections on methods and research design

We chose an exploratory research design to examine the diverse (cf. Seawright and Gerring, 2008) and contrasting bioeconomic cases of Germany and India; this design allowed us to inductively develop a model of how bioeconomic actors legitimize their technologies by means of narratives that are adjusted over time. We contributed to the study of imagined futures (Beckert, 2018) by showing that the content of narratives is context related (see Table 2 ; see Section 5.1 for a brief discussion on this aspect), while actors apply a similar set of strategies to stabilize, reject or adapt their narratives (see Section 4.3). Particularly, the discrepancies resulting from the different backgrounds of the two cases (one case is in the Global North, and the other is in the Global South) and their contrasting visions of the bioeconomy (cf. Bugge et al., 2016) allowed for conferrable findings that we consider transferable to other regions.

While we presented two contrasting cases to allow us to identify commonalities among the broad range of bioeconomies, we see further need to prove our resultant model of narrative dynamics through complementary research, such as through an analysis of cases from other regions and other bioeconomic contexts and visions (cf. Bugge et al., 2016). Moreover, a comparison of different national bioeconomic strategies promises fruitful insights at the international level. Additionally, the manifold kinds of uncertainty (i.e., risk, ambiguity, uncertainty, and ignorance) can be addressed in more detail in further research (cf. Stirling, 2010).

Altogether, our approach should be seen as a starting point of how to empirically access bioeconomic futures among the interviewed actors. Thus, the above-stated limitations also relate to the very nature of exploratory, inductive, qualitative research approaches that are focused on in-depth descriptions of new phenomena or on applying theory to practical examples. We encourage scholars to place much more emphasis on the role of imagined futures and fictional expectations relevant to sustainability science to uncover how prevalent uncertainties are managed and to see how and what futures are imagined to overcome these uncertainties. In our view, this is very relevant knowledge that can inform the management of not only bioeconomic but also sustainability transitions more broadly.

8.6 Conclusion

The aim of this article was to shed light on the imaginaries that shape bioeconomic innovation design and the co-constituted narratives employed by actors to legitimize technological innovations in the public. We found that these narratives inform different dynamics that can be triggered by irritations on discursive or political levels. Based on empirical material from two case studies on the bioeconomy in Germany and India, our research reveals a duality of both the highly resilient and mostly context-independent imaginary of a technological fix and highly dynamic, context-specific narratives. Against this background, we inductively developed a model that combines the notions of imaginaries, fictional expectations and narrative dynamics to serve as a guideline for future research.

We have argued that the imaginary of a technological fix is rooted in the logic of neoliberalism and is therefore deeply inscribed in society. As a result of this inscription, path dependencies may arise, provoked by mental lock-ins that culminate in a “colonization” of the future and that deem societal issues to be solved by technical solutions. We criticize such a reductionist perspective and propose the elaboration of a socioecological imaginary that limits technology to solving technical problems while accounting for societal and ecological issues to be solved by societal and ecological means. We therefore end by encouraging sustainability scholars to create open spaces for debate in transdisciplinary research projects that serve to jointly imagine futures and to develop solutions that can be dynamically adapted to ever-changing circumstances.

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9 Discussion and Synthesis

This research has investigated the socio-economic implications of the implementation of agricultural biotechnology for smallholders in the Global South by drawing on the example of Bt cotton technology in the context of rural India in Telangana. Taking the recent developments regarding the re-emergence of the target pest of Bt cotton technology into account, this study has provided substantial new insights into the altered vulnerability contexts of cotton-cultivating households. In so doing, this thesis has integrated hitherto unconsidered perspectives of marginalized actors into the scientific discourse surrounding biotechnology and GE crops. Thereby, this study has particularly shed light on the socio-biological embedding of agricultural biotechnology in general and Bt cotton in particular.

The thesis builds upon results generated by means of an exploratory mixed-methods research design, in which qualitative as well as quantitative research approaches were employed in close coordination with a broad spectrum of conceptual considerations. As such, my research provides a pluralized in-depth analysis of the socio-biological production of socio-economic risks and vulnerability of smallholders in rural contexts of biotechnological crop cultivation. Discussing both the empirical key findings affiliated with the realm of agri-food geographies as well as the conceptual involvement of this study, this chapter presents a synthesis of the scientific contributions compiled by this research via the articles and manuscripts portrayed in chapters 5-8 (cf. Najork et al. 2021, 2022; Friedrich et al. 2022; Najork and Keck (*forthcoming*).

9.1 Empirical research contributions

In a first step to investigate the socio-economic implications of the technology implementation of Bt cotton, I turned to Bt cotton-producing smallholders in the Indian state of Telangana to explore their perceptions and evaluations on the outcomes produced by the adoption of Bt cotton on their livelihoods. These qualitative perspectives were then, in a second step, complemented by quantitative insights to allow schematization and draw deductions on a broader scale. As such, this study is the first to provide empirical evidence on questions regarding the socio-economic consequences of the recent bollworm attacks in India. It has thereby contributed to fill the lacuna that had existed in the scientific debate surrounding Bt cotton technology in regard to questions concerning rural socioeconomy from a geographical perspective. These findings were then contextualized in further empirical phases by means of document analysis and the evaluation of expert interviews. The resultant deconstruction of their administrative and discursive embeddings disclosed the enmeshment of the socio-biological constitution of biotechnology.

9.1.1 Agricultural biotechnology and the production of vulnerability

First and foremost, this research makes clear that the PBW has returned to Bt cotton fields in rural Telangana after its hiatus of almost two decades. As both the qualitative and quantitative investigations of this thesis show, the vast majority of Bt cotton-farming households in the southern Indian state have faced severe pest infestations from the cotton season of 2015 and onwards (chapters 5-7). This outcome is hence in line with previous entomological studies that proclaimed re-occurrences of the technology's target pest in fields cropped with single- and dual-gene Bt cotton in central and southern Indian cotton-producing states (Naik et al. 2018; Fand et al. 2019; Mohan and Sadananda 2019; Tabashnik and Carrière 2019).

As the findings of this research outline, this development has changed the vulnerability context of Bt cotton-farming households substantially (chapters 5-6). While for the initial years of Bt technology implementation, farmers reported extensive uplifts in the form of yield improvements and pesticide reductions, lately, they have experienced severe setbacks. Smallholders initially experienced the adoption of Bt technology as an economic boom, which benefitted cultivators from diverse economic backgrounds alike, and thus enhanced rural wellbeing (chapter 5). These reports hence align with early agro-economic findings that are largely based on pre-2008 data and proclaimed yield increases, pesticide reductions, and resulting increases in farmers' income (Qaim 2003; Naik et al. 2005; Sadashivappa and Qaim 2009; Kathage and Qaim 2012; Plewis 2014). While some scholars argue that these positive effects are the isolated result of the technology's contribution (Qaim 2003; Kathage and Qaim 2012; Veettil et al. 2016), the findings of this study can neither confirm nor deny an exclusive attribution of such agronomic improvements to the Bt technology.

Yet, as both the qualitative and quantitative evidence provided by this study show, these initially reported positive effects were recently reversed by extensive re-occurrences of the PBW, with severe consequences for farmers' livelihood security, particularly for economically marginalized cotton smallholders (chapters 5-6). As I show in this research, the recent collapse in yields epitomizes the peak of an increasing unreliability of the Bt crop in the form of intensifying fluctuations in its output. This development significantly increases the risk associated with Bt cotton cultivation for smallholders. My empirical results thus add evidence to prior findings reporting higher production risks associated with Bt cotton cultivation (Glover 2010; Gaurav and Mishra 2012; Louis 2015). Moreover, based in the empirical setting of rainfed Telangana cotton production, my results are consistent with Gutierrez et al. (2015) who found increases in the vulnerability of farmers in rainfed areas due to the cultivation of Bt cotton (cf. Ramasundaram et al. 2007; Gutierrez 2018; Vasavi 2020; Matthan 2021).

While this research supports these previous studies by identifying increased production risks for smallholders, it also shows that further differentiation needs to be made in regard to the heterogenous vulnerability outcomes caused by such risks for the cotton peasantry (chapters

6-7). As this thesis shows, the impacts of an increased production risk vary according to farmers' coping and adaptation capacities, which in turn depend on their economic and asset-related preconditions. While resource-weak farmers face disproportionate limitations when it comes to accessing potential coping and adaptation strategies, economically better-off farmers are not (as) restricted in their coping and adaptation capacities. Already vulnerable Bt cotton-farming households are therefore disproportionately exposed to the shock of the technology's deficit and the resulting re-occurrences of the target pest (cf. Pal 2002; Vasavi 2014; Gutierrez 2018; Ramprasad 2019). These findings align with Louis (2015), who outlines a paradox in which the most resource-poor cotton farmers are constrained in their cultivation choice and simply cannot afford a diversified agriculture but are instead pushed toward high-risk cotton monocropping systems for the sake of short-term profit maximization.

These insights emphasize that within the heterogenous group of Telangana cotton farmers, some lose their investments, whereas others achieve to accumulate capital (Lerche 2013; Jakobsen 2018b). As shown in this research, these interdependent processes of lost investment and its appropriation lead to three mutually reinforcing consequences: (1) the process of ABD, (2) the reproduction of prevalent hegemonic structures, and (3) the development of an entrepreneurial mindset, in which farmers refrain from the compliance with Bt cotton refuge crop strategies.

As a first consequence, the mechanism described by Harvey (2005) as ABD gains momentum (chapters 5-6). However, as I have outlined in this thesis, the original approach focusing exclusively on farmland is insufficient to explain existing processes of ABD in the neoliberal Indian Bt cotton nexus and hence needs to be deduced to a more abstract level. Rather than being solely dispossessed of their land, I argue that farmers are primarily expropriated of their investments due to a cotton crop that is, at least in rainfed areas of cotton production, characterized by increased yield volatility. This process is paralleled by increased production risks for smallholders in which their investments deflagrate with every obsolescence of the agricultural biotechnology. Other actors in turn appropriate the released resources and capital is centralized.

The second consequence of the development described above is that this shift in capital resources reproduces hegemonic structures according to the originating economic preconditions of the involved actors (chapter 6) (cf. Jakobsen 2018b; Aga 2019; Brown 2019). As this research outlined, processes of accumulation in the neoliberal agri-food regime of Indian Bt cotton production generate beneficiaries and disadvantaged actors alike. These insights support the suggestions made by Brown (2019), who criticizes original agri-food regime analyses (Friedman and McMichael 1989; McMichael 2009), as these, according to the author, overemphasize resistance by subaltern classes. In accordance with Gramscian (1971) considerations of hegemony, this research shows that mechanisms of consent and coercion gain traction to reproduce the ruling position of dominant groups and thus guarantee the regime's stabilization (Simon 2015; Brown 2019). For this, the mobilization of intermediate classes is decisive, so that these local actors can reinforce a mediation of the regime's principles (Brown 2019). In the case presented here, this intermediate group, i.e., a rural elite, consists of those actors that profit in the outlined process of ABD by the appropriation of released resources of subaltern actors.

This heterogeneity of the Bt cotton peasantry yields yet another consequence when it comes to the compliance with Bt-related refuge policies (chapters 5 and 7). I show that an agrarian mindset focused on cotton monocropping is mostly followed by farmers located at the lower end of the economic spectrum, as this group of cotton farmers is pushed toward high-risk cotton monocropping systems for the sake of short-term profit maximization (cf. Louis 2015). In congruence with their orientation toward short-term economic benefits, these farmers refrain from growing refuge crops, as the cultivation of non-Bt refuge plants entails short-term economic sacrifices for farmers (Frisvold and Reeves 2008; Tabashnik et al. 2010, 2021; Kranthi et al. 2017; Wan et al. 2017; Mohan 2018). Ironically, it is thus this cotton monocropping-oriented producer type that contributes the least to sustain the long-term efficacy of the technology.

9.1.2 The socio-biological embedding of agricultural biotechnology

Apart from the findings on the biotechnological production of vulnerability for cotton-cultivating smallholders in Telangana, this research allows further deductions in regard to the entanglement of the agricultural technology with its socio-biological contexts. It has been progressively established in the scientific literature, e.g., in the realm of STS, that technologies never stand for themselves but are always embedded in their social context (Pinch and Bijker 1987; Callon 1987; Latour 2005; Jasanoff and Kim 2015). However, this understanding of technological contextualization remains insufficient to explain the enmeshments of Bt cotton technology. As this research makes clear, agricultural biotechnologies are not only entangled with social, but also with biological entities that have an influence on and are influenced by these technologies. My research thus reveals a threefold linkage of social, biological, and technological entities and eventualities (chapters 5-8).

While the use and innovation of Bt cotton are socially constructed and embedded, as the technology is produced in labs, implemented by farmers, and underlies public and scientific debates during its development and implementation process, I argue that it is further involved in biological contingencies that result from its endogenous biological qualities as well as its integration in exogenous biological linkages. Enmeshed in the biological dynamics of pest and host species, the technology provokes an arms race between farmers and target pests, in which the evolutionary pressure on the target pest automatically increases and the pest continuously develops new resistances in response. This understanding of a socio-biological embeddedness of technologies and agricultural biotechnologies in particular, illustrates the outdated notion of a human-nature divide and thus aligns with ontologies of STS and New Materialist streams of thought (cf. Haraway 1985; Latour 2005, 2017, 2018; Bennett 2010; Tsing 2018). My results hence align with Glover (2010, p. 502) who argues that the technology needs to be evaluated in practice, as it has to "function in particular socio-technical and institutional settings" and is not simply integrated "in the seed".

Against this background, I argue that the current form of Bt cotton technology includes an inherent socio-biological obsolescence which bears the risk of triggering a technology treadmill for farmers (Stone and Flachs 2017; Kranthi and Stone 2020; Luna 2020). I suggest that this obsolescence differs from planned obsolescence, which is common for neoliberal technologies in the manufacturing industries, but stress its parallels in that it generates similar outcomes in terms of an increased pressure on consumers to buy ever-new products, e.g., new seed technologies, in order to maintain the status quo (cf. Haribabu 2014; see also Harvey 2003, 2007). Finally, I argue that because of the biological contingency of the technology, its inherent obsolescence predicts a crisis trajectory for each newly produced generation of the current form of Bt cotton. The findings of this research thus clearly contradict the perception of Bt cotton technology as a sustainable "pro-poor" technology, as was claimed by proponents early on (cf. Sadashivappa and Qaim 2009; Kathage and Qaim 2012; Yadav et al. 2018; see also Glover 2010).

The above-outlined triune intertwining of social, biological, and technological factors is also revealed in my thesis by addressing mistranslations in the IRM strategies imposed by Indian authorities (chapter 7). Closely coordinated with the biological constitution of the target insect, the technology requires the implementation of Bt cotton refuge crops. However, as I show in this thesis, the implementation fails due to social contingencies epitomized by (1) an entrepreneurial agricultural logic, particularly of economically weak producers, and (2) mistranslations that occurred on the side of Indian policy-making authorities during the adaption of IRM strategies.

As my research shows, it is an entrepreneurial agricultural logic oriented toward short-term economic benefits prevalent in the subjectivity of farmers that underlies their non-compliance with refuge crop policies. This mindset is particularly present with economically weak producers, as, having no capacities to diversify their agricultural production, they are pushed toward high-risk cotton monocropping systems for the sake of short-term profit maximization (Louis 2015). Indian authorities have hitherto insufficiently considered this economic heterogeneity of Bt cotton producers regarding the compliance with refuge crop policies (Mohan 2017; Tabashnik and Carrière 2019; Tabashnik et al. 2021).

The social dependence of the technologically conformed but biologically integrated design of refuge crop policies is also revealed through mistranslations that occurred on the side of Indian authorities. While Indian policy-makers were oriented toward successful policy approaches of other countries, severe errors in translation occurred in the process of policy adaption, as the respective measures were only partially implemented by policy-makers (Tabashnik and Carrière 2019; Tabashnik et al. 2021). The aspired successful policies were thus never fully realized and resultingly, the Indian refuge policy implementation de facto failed. Thus, while this thesis indicates that social factors are critical and must be considered when implementing policies related to biotechnology, it also relieves farmers of the burden of bearing sole responsibility for the failed refuge policies in India.

Building on insights from economic sociology, the findings of this thesis allow further, if yet more abstract deductions regarding the socio-enmeshment of biotechnologies (chapter 8) (Beckert 2013, 2018; Bugge et al. 2016; Beckert and Bronk 2019). As this research deconstructs the co-constitution of imaginaries, fictional expectations, narratives, and innovation dynamics it suggests a contrast of fixed superordinate imaginaries on the one side and narrative dynamics on the other (Jasanoff and Kim 2009; Beckert 2018; Geels 2020). Thereby, this study shows how the internalized logics of involved innovation actors, e.g., the fixed imaginary of a technological fix, ultimately maintain their imagined futures. As such, the effect of social contingencies on (bio)technologies is again disclosed by this research. While I acknowledge the significance of imaginaries for the constitution of societal understandings and processes of collective decision-making (Ziegler 2019), I argue that the inflexible reliance upon technological fix imaginaries is reductionistic, as it ignores the threefold entanglement of social, biological, and technological entities unveiled by this thesis. With this contribution, this study emphasizes that it is decisive for relevant authority and innovation actors to take the socio-biological embeddings of agricultural biotechnologies in particular, and technologies in general, into consideration during the process of technology innovation and implementation in order to avoid mental and institutional lock-ins and remain vigilant in their conceptions of the future.

9.2 Methodological and conceptual research contributions

The above-outlined findings show that the concepts applied throughout this study were expediently implemented and yielded fruitful results that contribute to the debate surrounding GE crops and particularly Bt cotton in the Indian state Telangana from the perspective of agri-food geographies. Aside from its empirical contributions, this research adds to the concepts applied throughout the study. As such, it complements the theoretical and practical applications of the employed concepts, demonstrates ways of combining different methodological approaches and conceptualizations from varying epistemological origins, and thereby contributes to overarching theorizations of the discipline.

The study adds to action-oriented approaches from the realm of development studies, i.e., considerations of vulnerability and livelihood approaches, by shifting away from the original focus which often investigates natural disasters or hazards related to climate change (cf. Füssel and Klein 2006; Ford et al. 2018; IPCC 2022). Instead, this research looks at vulnerabilities that arise from the more gradual and mundane phenomenon of technological change, here in the form of agricultural biotechnology, and thus explores a hitherto less examined perspective of vulnerability research. In so doing, I highlight the importance of considering technological processes and their socio-biological entanglements in their potential to cause shocks for exposed households, particularly in countries of the Global South.

By exploring the role of GE crops in neoliberal rural Indian cotton agriculture, I further add to the theorization of variegated neoliberalism by Brenner et al. (2010). In their conception of neoliberalism, the authors emphasize that this economic model can take on various forms and can circulate through constitutively uneven processes and mechanisms (Harvey 2005; Ong 2007; Peck and Theodore 2007; Brenner et al. 2010). However, the specific role of biotechnologies in this development has hitherto received insufficient attention. In this research, I combine the considerations of a variegated neoliberalism by Brenner et al. (2010; see also Ong 2007; Peck and Theodore 2007) with Harvey's (2003, 2007) notion of a "technological fetish". Through this combination I contribute to the two conceptualizations, as I explicitly categorize (bio)technologies as one of many mechanisms in the nexus of a variegated neoliberalism. By outlining the role of technologies in this fragmentation, this thesis provides a realistic example of neoliberalization processes and critically assesses the risks accompanying the "fetish" belief in technological fixes.

By examining the role of neoliberal technologies in processes of capital accumulation this research extends political economic considerations (Harvey 2005; see also Marx 1967; Luxemburg 2003). The study builds upon but extends more recent research on the concept of ABD involving the agrarian capital expansion in countries of the Global South (Cáceres 2015; Cáceres and Gras 2020; Gras and Cáceres 2020) and the diffusion of GMOs in particular (Carroll 2017), as it goes beyond the focus on the appropriation of nature, but explicitly addresses the role of (bio)technology in processes of ABD in regard to the altered vulnerability context of Bt technology-applying farmers. As such, this study goes further than classical geographical studies of the concept that often focus on land grabbing as a mechanism of ABD (Levien 2012; Hall 2013; Gellert 2015; Zambakari 2018). The expropriating and simultaneous appropriating processes triggered by the implementation of neoliberal technologies are certainly more abstract in nature than corresponding processes of land grabbing. Yet, I argue that it is precisely the demonstration of a more abstract connection between accumulation and dispossession that characterizes the conceptual contribution of this research, as it helps to understand the complexity and diversity of ABD mechanisms, and outlines that also latent processes of the phenomenon need to be taken into scholarly consideration.

By outlining how accumulation cycles and class dynamics are coproduced, this research emphasizes the essentiality to consider perspectives of class and hegemony for an analysis of neoliberal agri-food regimes (Friedman and McMichael 1989; Lerche 2014; Jakobsen 2018b; Brown 2019). Based on the depicted entanglements of neoliberal technologies with agri-food regimes, this research suggests that it is vital to consider the role of technologies for regime-constituting hegemonic processes in such regimes. This study thus contributes to hegemonic conceptualizations by outlining how the constitution of neoliberal biotechnologies in their socio-biological embeddedness reproduces and stabilizes the prevalent hegemonic structures of the neoliberal Indian agri-food regime of Bt cotton production (cf. Gramsci 1971; Jakobsen 2018b; Brown 2019).

The original focus of the policy assemblages, mobilities, and mutations approach on urban spaces was extended by this research to a rural perspective as the concept was applied to the context of neoliberal rural Indian cotton production (cf. McCann 2011; McCann and Ward 2013; Savage 2020). By depicting the heterogeneous character of both policy-making on an administrative level and policy-implementing local actors, this research manages to retrace the relational dynamics that accompany processes of policy translation and their spatial outcomes, particularly in regard to biotechnology-related policies. Being entangled with socio-biological dispositions, the dynamics resulting from a failed or successful policy implementation of non-Bt refugia have direct effects on the spatial materiality of rural environments, i.e., technological longevity and related pest outbreaks in cotton fields, and with that entail immediate socio-economic consequences for farmers.

The conceptual contribution of this research to considerations of economic sociology lies in a generalizable model which illustrates the contrast of fixed superordinate imaginaries and narrative dynamics that are co-constituted in the imagined futures of bioeconomic innovation actors. This model is the result of an in-depth comparative analysis of two contrasting case studies, which aimed to deconstruct the co-constitution of imaginaries, fictional expectations, narratives, and innovation dynamics (cf. Jasanoff and Kim 2009; Beckert 2013, 2018; Beckert and Bronk 2019). As such, the research also succeeded in demonstrating the methodological advantages of contrasting case studies (cf. Seawright and Gerring 2008) in comparative analyses and with that made further methodological contributions.

9.3 Reflections and research limitations

Following an exploratory research design, I used different methodological approaches that I applied in coordination with a variety of conceptualizations (cf. fig. 1). In this way, my methodologically and conceptually multifaceted research approach aligns with considerations by Carolin Schurr on the theory development of human geography research in her keynote discussion with Peter Weichhart at the German Geography Congress in Kiel in 2019 (Schurr and Weichhart 2020). Schurr postulates a post-disciplinary geography in which manifold conceptual and theoretical approaches are used in order to "do justice to messy realities" (Schurr and Weichhart 2020, p. 57, own translation). According to Schurr, a versatile and "messy" canon of the human geographic discipline could contribute to avoid a stipulation of a hegemonic (colonial and masculine) canon (ibid., p. 59). With this position, she contrasts Weichhart, who criticizes an increased fraying of the theoretical basis of the human geographic discipline, without a central theoretical focus, but with the integration of ever-smaller conceptual streams. He thus accuses the discipline in its current form of randomly choosing conceptual and theoretical research approaches (ibid.). Schurr on the contrary claims that a pluralization of the discipline through smaller conceptual streams of hitherto underrepresented perspectives could lead to a desirable diversification, both in terms of researching subjects as well as researched objects, "from the margins" (ibid., p. 59). In this thesis, I show how this pluralization of conceptual and methodological approaches can be practically implemented in geographic research, and how this can lead to the revelation of perspectives that were hitherto marginalized in the scientific discourse. This research hence examplifies the benefits of a diversified approach, in that it allows for a multifaceted analysis of a problem that outlines its complex global-local interconnections.

Altogether, I applied various concepts and theorizations throughout my research, starting from more classic epistemological backgrounds, e.g., action-oriented approaches like vulnerability studies and livelihood approaches, to more recent conceptualizations, e.g., constructivist approaches like the STS-related policy assemblage approach or considerations from economic sociology (cf. Rauch 2018). I progressed by starting from a narrower focus on an individual micro-scale (i.e., individual farming households), for which I applied qualitative research methods in order to gain basic knowledge on the examined matter. I then expanded my focus to a structural meso-scale (i.e., a representative number of households) using quantitative research methods that aimed to facilitate schematization and allowed for generalizable deductions. Widening my perspective further to an administrative level, I used a methodological combination of document analysis as well as quantitative and qualitative empirical data. For an investigation of more diffuse processes located on a discursive level, I conducted a comparative analysis of two contrasting case studies from different countries (India and Germany) via an in-depth analysis of expert interviews. I combined concepts arranged on micro and macro levels in order to derive generalizable insights beyond the case study, e.g., action-oriented vulnerability / livelihood approaches on an individual scale combined with political economic considerations (ABD) on a structural scale; or policy assemblage approaches on an administrative scale combined with moral economic considerations on a micro scale. Covering a focused topic from varying angles of conceptual and methodological perspectives allowed for a comparison of empirical data. The acquisition and analysis of qualitative as well as quantitative data assured the accuracy of the varying data through triangulation.

This pluralization of conceptual and methodological approaches was particularly helpful for my research design, as it ensured the consideration of varying perspectives throughout the research process. This broad focus ensured that important aspects and perspectives were considered, even though I was not familiar with the empirical setting prior to my fieldwork. As such, it allowed me to re-arrange my focus towards the recent development of pest infestations emphasized by the interviewed farmers.

I thus turned to various classic as well as more recent concepts in coordination with different qualitative and quantitative research methods throughout the research. In so doing, I have demonstrated that a plethora of manifold conceptual and methodological combinations are applicable to yield fruitful results in geography studies, and with that made contributions to the discipline. I have made further methodological contributions by bringing long-neglected quantitative methods back into the discussion. The application of quantitative methods subsequent to a prior investigation by means of qualitative methods has enabled me to reveal marginalized perspectives, and still aggregate generalizable deductions on a superordinate structural level. I showed that a parallel and successive combination of qualitative and quantitative methods allows to explore the perspectives of subaltern actors without remaining stuck on a constricted local angle of analysis, but outline the global-local interconnections of complex problems.

This research hence underlines how the interdisciplinarity of the geographic discipline can be adequately addressed in regard to research design, its applied conceptualization, and employed methods. Thus, this thesis indicates that geography as an interdisciplinary field has to use various approaches from different schools of theory in order to do justice to its “messy” research objects. In this regard, the significance of inter- (cf. Rhoten 2004; Van Noorden 2015) and transdisciplinary research (cf. Zscheischler et al. 2018; Lawrence et al. 2022) must be emphasized. Interdisciplinary research seems particularly important in regard to the insights this thesis produced on the socio-biological embeddedness of technologies. The threefold entanglements found by this study suggest that combined efforts of natural and social sciences could yield insightful findings on the constitution, intertwining, and mututal influencing of varying aspects of focus in regard to (agricultural) biotechnologies. Moreover, this study’s findings concerning the altered vulnerability contexts of cotton smallholders indicate that a combination of scientific and non-scientific perspectives in the form of transdisciplinary research could allow even deeper insights, or provide yet other angles of perspective and thereby extend the results of this thesis.

With this research, I show that a pluralized integration of underrepresented and marginalized subaltern perspectives in the sense of a "geography from the margins" can be beneficial in regard to geographic research, both in regard to scientific outcomes that profit from a broader conceptual bouquet, but also with respect to the criticisms the discipline has faced regarding the debate on post-developmentalism in the subdiscipline of development geography (cf. Rauch 2018; Schlottmann 2018; Schurr and Weichhart 2020). In this connection, the subdiscipline had been accused of reproducing prevalent power asymmetries in current development discourses. Not least resulting from a western dominance in constituting research topics that are eligible for financing and their access to sources of funding, these "discursive asymmetries" (Gertel 2007, p. 65) often favor white and male perspectives of researchers from the Global North that hence maintain the sovereignty over the discourse (*Diskurshoheit*) (cf. Rauch 2018, p. 192). Against the background of these constructivist considerations, and taking into account that the research presented here benefited from (the combination of) multifaceted conceptual as well as methodological research approaches, I conclude by opting for the described pluralization of the discipline of development geography (Schurr and Weichhart 2020).

Despite the depicted benefits of this pluralized research approach, some limitations need to be addressed, too. While the diversified study focus allowed for valuable selected insights, a centralized conceptual as well as empirical focus would likely have produced a deeper analysis in some regards. Due to its broad focus, the thesis did, for example, not address the implications of the Bt cotton technology for smallholders on a larger geographical scale. Insights from other rainfed states would have provided a broader basis of comparison for the empirical data. Similarly, a comparison with data from irrigated states could have allowed for insightful contrasts. An expansion of the case study to other biotechnology implementing countries could certainly have produced valuable data regarding the influence of policies, e.g., crop insurance or refuge crop policies, on the livelihoods of smallholders. Also, expanding the focus to include other GE crops, such as GE food crops, could have provided further insight into the variance in effects of different GE crops on comparable livelihoods.

Additionally, analyzing altered vulnerability contexts and changes over time, a long-term cohort study would have provided a much more nuanced picture by exposing changes over time more adequately. I was, however, unable to take account of this potential for improvements, as the re-occurrence of PBW is a recent phenomenon in the cotton production of Telangana. It is therefore in the very nature of the subject matter that this study can only cover a relatively short time frame.

9.4 Outlook and recommendations for policy-making

Several recommendations for action emerge from the findings exposed in this thesis, and the reflections upon the same, for both policy-making state authorities as well as actors of the scientific and political community involved in the (agricultural) biotechnology debate and the Indian Bt cotton controversy in particular. To conclude the presented research, a list of such recommendations is outlined in the following. While these guidelines are derived from the analyzed case of the Indian Bt cotton sector, and therefore some of the presented recommendations are explicitly tailored to the case study and exclusively applicable to Bt technology, other recommendations can be transferred to contexts of other GE-implementing countries in the Global North and South.

Re-evaluation of Bt technology: As the analyses presented in this thesis confirm, we need to understand the target pest of Bt cotton as having returned to the crop's fields of Telangana. This recent development calls for a thorough re-evaluation of the Bt biotechnology as a whole. Whereas during the initial years of Bt implementation farmers reported agro-economic benefits, they now describe oscillating yields including severe collapses for some crop seasons. An agro-economic re-assessment of yields, pesticide usage, and further agro-economic figures which is based on current up-to-date data is therefore urgently needed. Further assessment is required for the socio-economic implications for farming households. While this thesis has started to re-evaluate the socio-economic implications of the recent developments in India's Bt cotton production and has addressed the void that has hitherto existed in the scientific literature in this regard, further re-assessment of the altered conditions of Bt cotton production through the technology's malfunctioning for farmers is required in other areas and over the long term.

Preventive monitoring measures: For a thorough re-evalutation of the technology and the monitoring of the recent target insect's outbreaks, it is imperative to implement preventive measures, too. These include consistent monitoring of the re-emerged pest outbreaks. The establishment of an independent body to conduct area-wide testing is thus essential to determine the long-term resistance levels of PBW to the endotoxins produced by the GE plant and to identify the extent of the infestations of the re-occurred moth in India. Furthermore, these preventive measures encompass the monitoring of the spatial and qualitative extent of infestations through other Lepidopteran pests, e.g., the ABW, and the surveillance of their resistance levels. On the plant's side, these preventive measures include the monitoring of the dosis of relevant endotoxins expressed by the induced genes (i.e., gene expression). This could support farmers with evidence that is needed to formulate claims for compensation from large seed corporations.

Crop insurances for Bt cotton farmers: The in-depth analyses provided in this research show that the cotton peasantry in India is diverse in regard to their financial and asset-related resources and limitations. As the economic pressure of agricultural performance on resource-restriced farming hosueholds is disproportionately high, it is essential to decrease the additional pressure created by volatile cotton yields and the related income fluctuations. State-funded crop insurances could provide relief for this vulnerable group of Bt cotton farmers. In this regard, policy-making political authorities also need to hold the technology distributing seed companies accountable by authorizing legal schemes that provide financial compensation for farmers in case of technological malfunctioning and resulting crop damage. Such mandatory compensation schemes, to which seed companies would have to adhere, could be a farmer-empowering protective mechanism that would equally benefit marginalized as well as resource-endowed farmers.

Targeted financial incentives for the cultivation of non-Bt cotton refuge crops: With respect to the cultivation of non-Bt cotton refuge crops, targeted financial incentives for adherence with IRM strategies could provide the necessary stimulus for farmers who follow an entrepreneurial agricultural logic to comply with the current refuge policies. Such financial incentives could lever out short-term economic maximization logics by, on the one hand, reducing short-term income losses caused by the cultivation of non-Bt refuge crops, and on the other hand, by remunerating an agricultural service that farmers have hitherto been expected to provide for free. The successful implementation of non-Bt refuge strategies could enhance the longevity of the Bt technology itself.

Expansion of IRM strategies to a multitactic approach: Simultaneous to the provision of financial incentives for farmers for the compliance with the present refuge policy, the expansion of the current unitactic approach to a multitactic IRM strategy is required. Implementation of this policy could help relieve farmers' shoulders of some of the burden of pest control and initiate an alignment of responsibilities in this regard. As outlined in this research, possible pathways of policy adoption could be either top-down in the form of government-organized and officially funded releases of sterile bollworm moths, as has been the case in the US; or through a bottom-up approach that continues to rely on farmers, but builds on the Chinese experience with an F_2 seed implementation that provides inherent financial incentives for farmers and an immanent non-Bt refuge. However, for both potential processes of policy adoption, the diverse local and administrative backgrounds need to be acknowledged: for the former top-down path of policy implementation, for example, the diverging economic resources of the two countries concerned, i.e., the US and India, have to be considered; for the latter bottom-up approach, it has to be taken into account that the PBW infestation levels that India currently faces are significantly higher than those in China before the (coincidental) implementation of the F_2 seeds. Therefore, a similarly successful policy outcome is not guaranteed.

Revising fixed imaginaries in the constitution of imagined futues: When it comes to tackling societal problems and challenges, I emphasize the significance of non-material societal constitutions in the abstract form of imagined futures. In this regard, it is essential that policy-making political and scientific actors as well as economic actors involved in the process of innovation creation and diffusion remain vigilant to avoid mental lock-ins and to overcome path dependencies. I hence opt for the consideration of social, cultural, and ecological factors in order to transcend the rigid neoliberal imaginary of a technological fix and effectively address societal problems that are non-technical in their origin. For the case of Bt cotton technology, this means to stay vigilant in regard to other agricultural technologies or non-technical approaches to improving agricultural production (e.g., organic cotton production, agro-ecological approaches, re-investigating traditional farming practices and in-situ knowledge).

Conducting a long-term cohort study: While this exploratory and pluralized research approach has provided fruitful results, more in-depth research is now necessary. While a long-term cohort study was hitherto impossible to conduct due to the recency of the subject, it is the next logical step in the process of investigating the implications of Bt technology implementation on smallholder cotton farmers. For this, the expansion of the geographical focus to other rainfed and even irrigated Indian states could yield valuable insights and allow for a broad basis of data comparison. Taking other GE crops into consideration would extend the focus of analysis and could thereby shed light on hitherto neglected aspects, such as the effects of GE food crop cultivation. Finally, research on GE crops altered in respect to abiotic factors promises to be interesting, particularly in light of the socio-biological enmeshment of agricultural biotechnologies revealed by this study.

Integrating inter- and transdisciplinary research approaches: Generally, future research on agricultural biotechnology could benefit from the integration of inter- and transdisciplinary research perspectives. The importance of incorporating multiple perspectives, i.e., various scientific disciplines as well as non-scientific perceptions, is underscored by this research. The indicated socio-biological constitution of GE crop technology, for example, promises to be a fruitful research object for interdisciplinary research by natural and social sciences. Building upon this research, a transdisciplinary combination of perspectives could then re-investigate the altered vulnerability contexts of farmers by integrating scientific and non-scientific actors. This could either result in deeper insights or generate new focal points in the analysis.

10 Conclusion

Located in the realm of agri-food geography, this thesis provides an up-to-date in-depth analysis of the implications of agricultural biotechnology on farming households and other relevant actors involved in the nexus of production, innovation, and policy-making processes of GE crops. Using the example of Bt cotton technology in the neoliberal Indian cotton sector, this study is the first to provide insights on the implications of the technology implementation on the rural socioeconomy of Bt cotton smallholders and the newly emergent pest outbreaks of the GE crop's target pest.

My empirical findings add to the evidence that confirms the return of the PBW to large parts of cotton cultivation areas in Telangana. While farmers still reported Bt-related benefits for the early years of the technology implementation, unexpected collapses in yields have now been ascertained. The findings of this study show that the re-occurrences of the insect have led to increased oscillations in Telangana cotton yields, and entail an augmented volatility in farmers' cotton-related effective income generation and the production of risk and vulnerability. However, these fluctuations are balanced only by economically better-off farming households, whereas resource-poorer farmers are pushed into debt and pressured into a cycle of dispossession. Especially these resource-poorer farmers are hence shown to be pushed toward a logic of short-term profit maximization through monocropping. In this way unveiling how the technology has changed cotton-farming households' vulnerability contexts, this thesis contributes to risk and vulnerability research. Having implemented a political economic perspective on the wider implications of the changed vulnerability context of farmers, it further contributes to current considerations of ongoing processes of ABD, particularly in countries of the Global South. My results suggest that while resource-poor farming households successively release capital due to losses incurred in the Bt cotton production, simultaneous opportunities of appropriation arise for other actors. Thereby, a process of capital centralization is triggerd in which low-income farmers are further marginalized. The still dominant narrative that depicts Bt cotton technology as a sustainable "pro-poor" technology is thus deconstructed by this research. The shift in capital resources consequentially affects the hegemony of the neoliberal agri-food regime of Indian Bt cotton production, as it reproduces prevalent hegemonic structures according to the originating economic preconditions of the involved actors. The resultantly stabilized economic heterogeneity in turn has an impact on the compliance with Bt cotton-related refuge policies. Here, I show that particularly farmers situated at the lower end of the economic spectrum often refrain from planting refuge crops, as these are associated with economic sacrifices. This economically heterogenous character of Bt cotton farmers has, however, been hitherto neglected by Indian state authorities and should urgently be taken into consideration. Moreover, this study unravels the administrative side of the refuge policy assemblage and thereby debunks serious mistranslations that went along with the adaption of Bt cotton-concerning IRM strategies on the side of state authorities. Finally, this study exposes essential qualities of the constitution of imagined futures that underly processes of biotechnological innovation but also shape the on-site rural socioeconomy of technology-implementing farmers. This research empirically contributes by disclosing the contrast of fixed imaginaries and narrative dynamics which in sum results in the prevalence of internalized logics of a (bio)technological fix. This rigid conception of the future entails the risk of mental and institutional lock-ins with detrimental effects on smallholding producers.

Conceptually, the study makes further contributions to the discipline of geography. It adds to vulnerability research by shifting away from the original focus which often investigates shocks caused by natural disasters or hazards, as it instead highlights the potential of technology implementation and its socio-biological enmeshment to cause shocks for exposed households, particularly in countries of the Global South. It further emphasizes the role of technologies in processes of neoliberalization as it characterizes (bio)technologies as a mechanism of variegated neoliberalism. By examining the role of neoliberal technologies in processes of capital accumulation this research extends political economic considerations by outlining the significance to consider latent processes of the phenomenon. As such, it helps to understand the complexity and diversity of ABD mechanisms. In depicting how accumulation cycles and class dynamics are co-produced, this research emphasizes the essentiality to consider perspectives of class and hegemony for an analysis of neoliberal agri-food regimes. Hegemonic conceptualizations are thus extended by emphasizing that the constitution of neoliberal biotechnologies in their socio-biological embeddedness reproduces prevalent hegemonic structures. The conceptual contribution of this research to economic sociology research on imagined futures lies in a generalizable model which illustrates the co-constituted contrast of fixed imaginaries and narrative dynamics.

Implementing a manifold set of conceptual as well as methodological combinations, this research provided a pluralized in-depth analysis of the socio-biological production of socio-economic risks and vulnerability of smallholders in rural contexts of biotechnological crop cultivation. The study explored the effects of Bt cotton technology at different levels of analysis and contributes to the scientific debate surrounding Bt technology by expanding our knowledge on hitherto marginalized perspectives on the rural socioeconomy of Bt cotton smallholders. As is demonstrated by the fruitful results yielded by this study, geography research can benefit from a pluralization of approaches, because only then can a problem be understood in its complex global-local interconnections, and in the case of Bt cotton technology, the linkage of social, biological, and technological entities and eventualities.

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Appendix

Appendix 1: Qualitative Interview Guide

Livelihood

What does your livelihood consist of?
- How many and which people belong to your household?
- What is their occupation? Education, age, household income?

Agriculture

What kind of agriculture do you conduct?
- What is the ***size of land*** you use for agriculture? How much of it is ***owned/leased***?
- Which ***HH members*** work ***on*** your ***farm***? What are the other HH members doing?
- What sorts of ***field crops*** you grow around the year? In what ***volumes*** (or proportions) do you produce ***cash/subsistence crops***?
- What ***type of cotton*** do you cultivate? Why and since when? Please give reasons. Did anyone recommend this particular type of seeds to you?
- Do you plant ***trap rows*** (refuge) around your Bt cotton field?
- Do you ***hire labor*** for agriculture related activities? In what season? What are their tasks?

Vulnerability and Shocks

How do you cope with shocks?
- I learned that 2016/17 was a bad season for cotton and many farmers in Telangana suffered notable losses due to a return of pink bollworm. Please explain how your ***production was affected*** by the pest. How much of your production did you lose? Were there differences in the quality of your yield?
- ***How did you cope*** with the losses you suffered? Did you have other ***compensatory crops*** that you could get profits from?
- Did you have to get ***loans***? Who did you get the loans from (bank, commission agent, miller)? Did you ***borrow money*** from friends or family? ***Are you still in dept*** due to the crisis of 2016/17?
- Did you ***consult with other farmers*** in the village about the crisis? What to do about it, how much they have suffered, how they coped?
- Actually, Bt cotton is supposed to be resistant to pink bollworm. However, the crisis in 2016/17 was caused by pink bollworm. Do you see an ***evolving resistance*** in pink bollworm towards Bt cotton in the last years?
- Many Bt cotton seeds producing companies blamed farmers for the crisis in 2016/17. They argue that the pink bollworm pest came back because farmers did not follow the instructions properly and did not put up sufficient ***trap rows***. Do you agree?
- What did you ***learn from the crisis***? Are you going to change anything in your cultivation of cotton and altogether?
- What do you wish for your ***children***? Do you want them to become farmers as well?

Evaluation of Bt Cotton Cultivation

Would you regard the adoption of Bt Cotton as rather positive or rather negative?

- The Government of India praises Bt cotton as technology suitable to increase farmers' income and to improve agriculture. How do you personally ***evaluate*** Bt cotton? Are you ***proud*** to be part of this technological revolution?
- Do you recognize an increase in ***income*** since cultivating Bt cotton? Do you see a reduction of ***vulnerability*** regarding pests and other natural calamities since cultivating Bt cotton?
- Would you agree that your ***all-day life has changed*** because of Bt cotton? Could you afford any ***new notable purchases*** due to Bt cotton? Can you afford ***better schooling*** for your children or ***better health care*** for your family?
- The government recently introduced a platform (Application, website) called ***NAM*** (National Agriculture Market). Did this help you in any way to gain power regarding the negotiation of prices? Do you still need a commission agent in order to sell your produce?

Knowledge and Learning

How did/do you learn to conduct your agriculture-related tasks?

- What are your main ***sources of information*** regarding agriculture-related activities?
- What ***kind of information*** do you get there?

Bt III

What do you know about the illegal market entry of Bt III seeds?

- Have you heard that it is debated whether the successor of Bt II, ***Bt III, should be commercialized***? What is your opinion on this matter? Do you think that this new technology could improve your yield?
- Have you heard about ***seed shops*** that already sell Bt III seeds? Have you heard about ***farmers*** who are already growing Bt III?
- Have you heard of ***employees of seed companies*** who distribute these seeds directly to farmers?
- Some farmers reported that the ***plant size last year*** was much less than the year before. Some are blaming faulty seeds, some claim that they used Bt III seeds and these did not grow properly. Have you heard about these rumors?
- Have you ever used Bt III seeds?

Appendix 2: List of qualitative interviews

Appendix Table 1: List of qualitative interviews

No*	Name	Expertise	Landholding size	Date
V01-I01	**Mari Jagan** (m)	Peasant	11 acres owned: paddy, cotton, chili	10.09.18
V01-I02	**Mahendra** (m)	Peasant	7.5 acres owned: paddy, cotton	11.09.18
V01-I03	**Mamatha** (f)	Peasant	7.5 acres owned: paddy, cotton	11.09.18
V01-I04	**Karmagala Lakshmi** (m)	Peasant	11 acres owned: paddy, cotton, turmeric	11.09.18
V01-I05	**Parameshwari** (f)	Peasant	11 acres owned: paddy, cotton, turmeric	11.09.18
V01-I06	**Mari Jagan** (m)	Peasant	11 acres owned: paddy, cotton, chili	11.09.18
V01-I07	**Lavanya** (f)	Peasant	11 acres owned: cotton, maize, turmeric	11.09.18
T01-I01	**Satish** (m)	KVK representative		12.09.18
T01-I02	**Mukka** (m)	Cotton mill owner		12.09.18
V01-I08	**J. Mala** (m)	Peasant	No owned land, hired laborers	12.09.18
V01-I09	**Gujala** (f)	Peasant	No owned land, hired laborers	12.09.18
V01-I10	**Pulajillala** (f)	Peasant	No owned land, hired laborers	12.09.18
T01-I03	**Krishnamurthy Ch.** (m)	Inputs shop owner		13.09.18
V01-I11	**Jelander** (m)	Peasant	1 acre owned: cotton, paddy	13.09.18
V01-I12	**Rama** (f)	Peasant	50 guntas owned: cotton, paddy	13.09.18
T01-I04	**Tirupaddy** (m)	Commission agent		14.09.18
V02-I01	**P. Ravindar** (m)	Peasant	6.5 acres owned: cotton, paddy, on lease	17.09.18
V02-I02	**Ram** (m)	Peasant	3 acres owned: cotton, paddy	18.09.18
V02-I03	**Lakshmi Srinivas** (m)	Sarpanch		18.09.18
V02-I04	**Mugula** (m)	Peasant	8 acres: 4 acres owned, 4 acres leased: paddy, cotton	18.09.18
V02-I05	**Thirupati** (m)	Peasant	6 acres owned: cotton, paddy	18.09.18
V02-I06	**Damodar** (m)	Peasant	1.5 acres owned: cotton	18.09.18
V02-I07	**Mahindar** (m)	Peasant	4 acres owned: turmeric, chili, paddy, cotton	18.09.18
V02-I08	**Tirupati G.** (m)	Peasant	5 acres: 2 acres owned, 3 acres leased: cotton, paddy	18.09.18
V02-I09	**Parusharam** (m)	Model farmer	10 acres: 5 acres owned, 5 acres leased: cotton, paddy	19.09.18
V02-I10	**Md. Rahimodhin** (m)	Peasant	4.5 acres: cotton, paddy	19.09.18
V02-I11	**Kasturi** (m)	Peasant	8 acres: 6 acres owned, 2 acres leased: cotton, paddy	19.09.18
V02-I12	**N. Venkateshwarlu** (m)	Peasant	24 acres owned: cotton, paddy, on lease	19.09.18
V02-I13	**Mohamad** (m), **Jarina** (f)	Peasants	2 acres owned: cotton, paddy	19.09.18
V02-I14	**Sanjeev** (m)	Peasant	1 acre owned: cotton	19.09.18

T02-I01	**Vijay Reddy** (m)	Inputs shop owner		23.09.18
V03-I01	**N. Raju** (m)	Peasant	15 acres: 5 acres owned, 10 acres leased: cotton, maize	24.09.18
V03-I02	**Kalakonda Narasimha** (m)	Peasant	20 acres owned: cotton, maize, paddy	24.09.18
V03-I03	**C.H. Narayana** (m)	Peasant	5 acres: 4 acres owned, 1 acre leased: cotton	24.09.18
V03-I04	**Ramana** (m)	Peasant		24.09.18
V03-I05	**Karra Srinivas** (m)	Peasant	16 acres: 1 acre owned, 15 acres leased: cotton, maize, paddy	24.09.18
V03-I06	**Chiluka** (m)	Peasant	8 acres: 6 acres owned, 2 acres leased: cotton, paddy	24.09.18
V03-I07	**Naran** (m)	Peasant	10.5 acres: 1.5 acres owned, 9 acres leased: cotton, maize	24.09.18
V03-I08	**Mandhala Linga** (m)	Peasant	18 acres owned: cotton, paddy	24.09.18
V03-I09	**Raj** (m)	Peasant	9 acres: 6 acres owned, 3 acres leased: cotton, paddy	25.09.18
V03-I10	**Janardan** (m)	Peasant	6 acres owned: cotton, paddy	25.09.18
T03-I01	**Tharun** (m)	Seed production enterprise		26.09.18

* “V”stands for village; “T” stands for town; “I” stands for interview partner

Appendix 3: Survey Questionnaire

Section A: **Socio-economic data**

This group of questions aims at gaining information about the general socio-economic data of the household.

A1. **Please state the gender and age of all household members.**

E.g.: m36

Person 1 (household head)
Person 2
Person 3
Person 4
Person 5
Person 6
Person 7
Person 8
Person 9
Person 10
Person 11
Person 12
Person 13
Person 14
Person 15
Person 16
Person 17
Person 18
Person 19
Person 20

A2. **Please state the number of generations living in this household.**

E.g.: grandfather, father and mother, two sons = 3

A3. **Please select the highest education of the household head.**

no education
alphabetized
finished primary school
secondary school certificate (S.S.C.)
higher secondary certificate (H.S.C.)
holding a university degree (Bachelor, Master, PhD)
Other

Other

A4. **Please enter the number of household members contributing to household income.**

Section B: **General agriculture-related data**

This group of questions aims at gaining an overview over the household's agricultural production (not only (Bt) cotton).

B1. **What is the size of the farmland that you are currently cultivating? [acres]**

1 guntha = 0.025 acres

10 gunthas = 0.25 acres

B2. **How much of the farmland you cultivate do you own? [acres]**

1 guntha = 0.025 acres

10 gunthas = 0.25 acres

B3. **In the current season, on how much of your farmland do you grow cotton? [acres]**

1 guntha = 0.025 acres

10 gunthas = 0.25 acres

B4. **Which (other) crops do you grow?**

Please use a comma to seperate, for example: maize, turmeric, paddy, ...

Section C: **Bt cotton**

This group of questions aims at gaining deeper knowledge about the household's cotton production.

C1. **Are you currently growing bt cotton?**

Yes
No
Not aware of what he/she grows
No answer

C2. **Have you ever grown Bt cotton?**

Yes
No

C3. **Please explain in detail why you stopped growing Bt cotton.**

C4. **For how long have you been growing Bt cotton? [in years]**

C5. **What kind of seeds do/did you use per year? Please give us the exact name (brand name & type of seed) per year.**

Please let farmers take their time to think about this question. It might take some time to remember the brands and types of the past five years.

Abbreviation for 'see above': s.a.

If a farmer cannot answer the question, please write N/A

Year 2014
Year 2015
Year 2016
Year 2017
Year 2018
Year 2019

C6. **Did you change from Bt I to Bt II seeds? Please specify the year of change.**

Please enter the year of change in the comments

If the farmer is not aware whether he/she grows Bt I or Bt II, please tick 'no answer'.

Yes
No

C7. **Why did you change from Bt I to Bt II?**

C8. **Did you change from Bt II to Bt III seeds? Please specify the year of change.**

Please enter the year of change in the comments

If the farmer is not aware whether he/she grows Bt I or Bt II, please tick 'no answer'.

Yes
No

C9. Why did you change from Bt II to Bt III?

C10. How did you become aware of Bt II, Bt III?

- Fellow farmer ☐
- Shop keeper ☐
- KVK ☐
- Model farm ☐
- Friends and relatives ☐
- TV, Internet, Magazines ☐
- not aware of Bt II/ Bt III ☐
- Other ☐

Other

C11. Has your acreage used for Bt cotton changed compared to the previous year within the past 5 years?

	Year 2014	Year 2015	Year 2016	Year 2017	Year 2018
strong increase	☐	☐	☐	☐	☐
increase	☐	☐	☐	☐	☐
steady	☐	☐	☐	☐	☐
decrease	☐	☐	☐	☐	☐
strong decrease	☐	☐	☐	☐	☐

C12. Please give reason for the changes.

If there are no changes, please write 'steady'.

C13. Describe your Bt cotton related yield (yield per acre) from 2014.

	Year 2014	Year 2015	Year 2016	Year 2017	Year 2018
very good	☐	☐	☐	☐	☐
good	☐	☐	☐	☐	☐
moderate	☐	☐	☐	☐	☐
bad	☐	☐	☐	☐	☐
very bad	☐	☐	☐	☐	☐

C14. Please give reasons for any changes.

If there are no changes, please write 'steady'.

C15. Describe your Bt cotton-related income within the past 5 years.

	very good	good	moderate	bad	very bad
2014	☐	☐	☐	☐	☐
2015	☐	☐	☐	☐	☐
2016	☐	☐	☐	☐	☐
2017	☐	☐	☐	☐	☐
2018	☐	☐	☐	☐	☐

C16. Please give reasons for any changes.

If there are no changes, please write 'steady'.

C17. Have you been increasing/decreasing your pesticide usage during the past 5 years compared to the previous year?

	Year 2014	Year 2015	Year 2016	Year 2017	Year 2018
strong increase	☐	☐	☐	☐	☐
increase	☐	☐	☐	☐	☐
steady	☐	☐	☐	☐	☐
decrease	☐	☐	☐	☐	☐
strong decrease	☐	☐	☐	☐	☐

C18. Please give reasons for any changes.

If there are no changes, please write 'steady'.

C19. Have you been increasing/decreasing your fertilizer usage during the past 5 years?

	Year 2014	Year 2015	Year 2016	Year 2017	Year 2018
strong increase	☐	☐	☐	☐	☐
increase	☐	☐	☐	☐	☐
steady	☐	☐	☐	☐	☐
decrease	☐	☐	☐	☐	☐
strong decrease	☐	☐	☐	☐	☐

C20. Please give reasons for any changes.

If there are no changes, please write 'steady'.

C21. Have you ever experienced one of the following issues related to the Bt cotton seeds you were using?

- not germinating seeds ☐
- not growing seeds ☐
- low yielding seeds ☐
- Never had any problems with the seeds ☐
- Other ☐

Other

C22. Please specify brand and year, if possible.

C23. Do you generally grow a second season on your Bt cotton fields?

- Yes ☐
- No ☐

C24. Which additional crop(s) do you grow?

C25. **Why do you not grow a second season on your fields?**

C26. **If officially approved, would you use Bt III cotton seeds?**

Yes ☐
No ☐

C27. **Please give a reason for your decision.**

C28. **If approved, would you grow Bt food crops (e.g. Bt brinjal)?**

Yes ☐
No ☐

C29. **Please give a reason for your decision.**

Section D: Pink Bollworm

This group of questions aims at gaining deeper knowledge about the (potential) effects of pink bollworm on the household's cotton production.

D1. **Have you ever faced the infestation of pink bollworm on your cotton fields?**

Yes ☐
No ☐

D2. **In which year did you face the return of pink bollworm in your cotton fields?**

D3. **Did you take up a loan due to the losses caused by pink bollworm within the past 5 years?**

Yes ☐
No ☐

D4. **In which of the past years did you take up a loan due to yield losses caused by pink bollworm?**

For comments: if possible, please (1) specify the total sum of the loan and (2) the source of the loan (formal: bank; informal: relatives).

2014 ☐
Comment

2015 ☐
Comment

2016 ☐
Comment

2017 ☐
Comment

2018 ☐
Comment

2019 ☐
Comment

D5. **Are you still indebted from the last shock?**

Yes ☐
No ☐

D6. **Did you change your agrarian production after the occurrence of pink bollworm?**

reduced acreage under cotton ☐
Comment

changed brand ☐
Comment

changed seed type from the same brand ☐
Comment

increased acreage under cotton ☐
Comment

I did nothing ☐
Comment

other ☐
Comment

D7. **Have you tried to get compensation for your loss from seed companies?**

Yes ☐
No ☐

D8. **Did you actually get compensation?**

Yes ☐
No ☐

D9. **Why did you not try to get compensation?**

D10. **From which company did you try to get compensation?**

D11. **Within the past 5 years, how often and how severely did the following issues affect your cotton production? frequency**

	five times	four times	thrice	twice	once	never
pink bollworm	☐	☐	☐	☐	☐	☐
sucking pest	☐	☐	☐	☐	☐	☐
drought	☐	☐	☐	☐	☐	☐
untimely rains	☐	☐	☐	☐	☐	☐
soil degradation/erosion	☐	☐	☐	☐	☐	☐
lack of access to irrigation (e.g. canal system or open well)	☐	☐	☐	☐	☐	☐
spoiled seeds	☐	☐	☐	☐	☐	☐
weeds	☐	☐	☐	☐	☐	☐
lack of available labour	☐	☐	☐	☐	☐	☐

D12. Within the past 5 years, how often and how severely did the following issues affect your cotton production? severity

	severe impact	slight impact	no impact
pink bollworm	☐	☐	☐
sucking pest	☐	☐	☐
drought	☐	☐	☐
untimely rains	☐	☐	☐
soil degradation/erosion	☐	☐	☐
lack of access to irrigation (e.g. canal system or open well)	☐	☐	☐
spoiled seeds	☐	☐	☐
weeds	☐	☐	☐
lack of available labour	☐	☐	☐

D13. Feel free to comment your answer.

Section E: Refuge Crops

This group of questions aims at geining a deeper understanding of the (non) implementation of refuge crops.

E1. In your opinion, what is the purpose of the seed package attached to Bt cotton seeds?

Please show the provided picture to the farmers and give them enough time to think about the question.

E2. Have you been informed to plant refuge crops?

Explanation to farmers: refuge crops can be grown from the non-Bt seeds provided in the package attached to Bt seeds

Yes ☐
No ☐

E3. Who informed you to plant refuge crops?

E4. Have you been growing refuge crops during the past 5 years?

Yes ☐
No ☐

E5. Imagine your field: Where exactly do you plant refuge crops?

Here, both the amount of refuge (for example, number of rows or ratio [95:5]) as well as the position in the field (for example, within the field or outer circle of the field) are of importance.

E6. Why not?

E7. Have you been growing refuge crops at any point of your Bt cotton production history?

Yes ☐
No ☐

E8. Why did you stop growing the refuge?

E9. Did you notice that seed companies have started to sell non Bt seeds and Bt seeds in the same package?

Yes ☐
No ☐

Section F: Acces to Knowledge and Markets

This group of questions aims at gaining a deeper understanding of the acquisition of knowledge and information as well as the access to markets.

F1. From where do you obtain your seeds?

Only fill out comment column for chosen answers. Then, fill out column in regard to name of shop vs. village/town name, distance.

shop
Comment

mobile distributor
Comment

other farmers
Comment

landlord
Comment

Other
Other

F2. In your choice of seeds, are you oriented towards one of the following?

Only fill out comment column for chosen answers. Then, fill out column in regard to name of shop vs. village/town name, distance.

fellow farmers
Comment

KVK
Comment

input shop owner
Comment

TV shows
Comment

Internet
Comment

magazines ☐

Comment

other ☐

Comment

not oriented towards other influences ☐

Comment

F3. Have you ever been a model farmer?

Yes ☐

No ☐

F4. Was this beneficial to you?

Yes ☐

No ☐

F5. How was this beneficial for you?

F6. Why was it not beneficial for you?

F7. Where did you get your knowledge regarding (Bt) cotton cultivation from?

Only fill out commentary column if answer was chosen. If chosen, please consider:

for TV: TV shows for internet homepage: please specify the institution for social media: please specify: which app or youtube channel, etc.

Television ☐

Comment

Internet homepage ☐

Comment

Magazines ☐

Comment

Fellow farmers ☐

Comment

Friends or relatives ☐

Comment

Model farm ☐

Comment

Inputs shop ☐

Comment

Social Media ☐

Comment

Other ☐

Other

F8. Do you maintain regular contact with a farmers' association?

examples: Centre for Sustainable Agriculture (CSA), Consortium of Indian Farmers Association (CIFA), Bharatiya Kisan Sangh (BKS)

Yes ☐

No ☐

F9. Which one(s)?

F10. How is this beneficial for you?

F11. Do you know of any active agriculture-related NGOs in your village/area?

examples: Deccan Development Society (DDS), Gene Campaign,...

Yes ☐

No ☐

F12. Which one(s)?

F13. Please specify how they were active.

F14. Have you ever approached extension services?

extension services are f. ex. the Krishi Vigyan Kendra (KVK).

Yes ☐

No ☐

F15. What did you approach them for?

F16. Why/How do you find them helpful?

F17. Why not?

F18. Which way do you sell your produce?

market: open auction ☐

commission agent ☐

cotton miller (direct) ☐

e-Market system ☐

CCI (Cotton Corporation of India) ☐

contract ☐

Other

Other

F19. Are you satisfied with the way you sell your produce?

Yes ☐
No ☐

F20. Why are you satified with it?

F21. Why are you not satisfied with it?

Section G: Statement Questions

This section tries to explore impressions rather than hard facts.

G1. Please rate the following statements.

risk: for example, higher input costs and higher probability of failure.

	Strongly agree	Agree	neither nor	Disagree	Strongly disagree
In regard to the amount of required inputs, Bt cotton is more efficient than non-Bt cotton.	☐	☐	☐	☐	☐
Bt cotton requires more hired labour than non-Bt cotton.	☐	☐	☐	☐	☐
Throughout the past 2 years, Bt cotton has lost its efficacy.	☐	☐	☐	☐	☐
Bt cotton used to be resistant against pink bollworm in the past.	☐	☐	☐	☐	☐
Bt cotton is still as resistant against pink bollworm as it used to be.	☐	☐	☐	☐	☐
When I started using Bt cotton, my income situation noticeably improved.	☐	☐	☐	☐	☐
Bt cotton still improves my income situation noticeably.	☐	☐	☐	☐	☐
Bt cotton's performance is reliable.	☐	☐	☐	☐	☐
Since I use Bt cotton, the risk of production has increased.	☐	☐	☐	☐	☐
I am considering to reduce my acreage of Bt cotton cultivation.	☐	☐	☐	☐	☐
Would you agree that the shortening of the season through the cultivation of Bt cotton is beneficial for your business?	☐	☐	☐	☐	☐
When I plant Bt cotton, I follow the instructions printed on the seed packages and plant refuge crops.	☐	☐	☐	☐	☐
All farmers follow the instructions printed on the seed packages and plant refuge crops.	☐	☐	☐	☐	☐
Since none of my fellow farmers plant refuge crops, why should I?	☐	☐	☐	☐	☐
The planting of refuge crops reduces my potential yields and earnings.	☐	☐	☐	☐	☐
If I got compensations/financial incentives to grow a refuge, I would grow it.	☐	☐	☐	☐	☐
Seed companies are ripping off farmers by mixing non Bt seeds and Bt seeds within the same package.	☐	☐	☐	☐	☐
Since many farmers do not grow refuge crops, it is necessary that non Bt and Bt seeds are mixed and sold within the same package.	☐	☐	☐	☐	☐
If I had the choice, I would prefer to grow non Bt cotton.	☐	☐	☐	☐	☐

Section H: General Information

In this section, general information is entered by the interviewer.

H1. Please fill in the date.

H2. Please enter the initials of the interviewer/surveyor and number of the questionnaire.

Example: KN001

H3. Please enter the code of the village.

V1 ☐
V2 ☐
V3 ☐
V4 ☐
V5 ☐
V6 ☐
V7 ☐
V8 ☐
V9 ☐
V10 ☐
V11 ☐
V12 ☐
V13 ☐
V14 ☐
V15 ☐
V16 ☐
V17 ☐
V18 ☐
V19 ☐
V20 ☐
V21 ☐

H4. Please enter the GPS identification mark of the household.

Format: village code, initials of surveyor, no. of questionnaire.

E.g. V1KN001

Thank you for your participation and cooperation! Your responses are very helpful for us.

Appendix Figure 1: Compilation of Survey Questionnaire

Appendix 4: Quantitative Sample Composition

Appendix Table 2: Quantitative Sample Composition

District	Mandal	Village	Population	No. HHs	n
Adilabad	Wankdi	1	1009	223	10
Adilabad	Wankdi	2	1854	405	18
Adilabad	Kagaznagar	3	2665	687	31
Adilabad	Kagaznagar	4	2304	575	26
Adilabad	Bhimini	5	1292	344	16
Warangal	Parkal	6	3261	853	38
Warangal	Duggondi	7	3729	1026	46
Warangal	Duggondi	8	2761	743	33
Warangal	Duggondi	9	2723	730	33
Warangal	Duggondi	10	3305	953	43
Nalgonda	Chandur	11	2907	759	34
Nalgonda	Chandur	12	2147	501	23
Nalgonda	Devarakonda	13	2796	665	30
Nalgonda	Narayanapu	14	5663	1415	63
Nalgonda	Narayanapur	15	1173	288	13

Appendix 5: Expert Interview guideline

Technological development

1. What major progress Indian companies have made in the last years in developing GM technologies?

2. From your practical experience, how important is farmers knowledge to provide sellable seed products? [for seed companies: How do you ensure that your products are valued by farmers?]

3. Given your expertise, are there new ways necessary for measuring the risk of GM technologies? What is your advice on how do you deal with remaining uncertainties (e.g., precautionary principle vs. “postcautionary principle)?

4. From your perspective, what future steps need to be achieved in GM biotechnology to improve the livelihoods of Indian farmers and the food security of Indian people (besides Bt rice and herbicide tolerant maize)?

Political process

1. Given your expertise, do political decision makers in India comprehend the potentials and risks of GM biotechnology correctly?

2. From your perspective what would there need to be changed in the Indian market for Indian companies to get a stand in GM technologies and to compete with international companies?

3. What are Indian biotech companies do for overcoming the regulatory hurdles that you mention?

4. Andhra Pradesh is currently not giving the NOC (no objection certificate) for field trials on Bt rice, which became mandatory in February 2010. What are the reasons behind? Who is responsible for this decision? What is the latest stand on the NOC issue in Telangana?

6. In your opinion, who are the powerful actors deciding upon the future of GM biotechnology in India: (international) NGOs (Navdanya, Greenpeace, CSA, DDS), private companies (Metahelix, ABLE), political parties (e.g., via their farmers organizations)?

7. What are the major juridical changes since the commercialization of Bt cotton that affect the development of GM seeds in India?

Motivation and future anticipations

1. How realistic do you consider the future of GM technologies in the Indian agriculture?

2. What is your personal motivation to promote GM technologies in the Indian agricultural sector?

Appendix 6: List of expert interviews

Appendix Table 3: List of expert interviews

No.	Name	Organization	Date
1	Dr. G. V. Ramanjaneyulu	Executive Director, Centre for Sustainable Agriculture (CSA)	19.09.2017
2	Dr. Rukmini Rao	Director, Deccan Development Society (DDS)	20.09.2017
3	Mr. P. Chengal Reddy	Chairman of Consortium of Indian Farmers Association (CIFA)	11.02.2018
4	Dr. K. K. Narayanan	Managing Director of Metahelix Life Sciences; Member of task force "Agricultural Biotechnology", working group "Biosafety Regulations" of Department of Biotechnology (DBT), Government of India; Member of executive council of Association of Biotechnology Led Enterprises (ABLE)	15.02.2018
5	Prof. Dr. E. Haribabu	Department of Sociology, University of Hyderabad	16.02.2018
6	Subhra Priyadarshini	Editor, Nature India	19.02.018
7	Vijoo Krishnan	All India Kisan Sabha (AIKS; partner organization of Communist Party of India – Marxist (CPI (M)), Head of Department of Post Graduate Department of Political Science St. Joseph's College Bengaluru, former President of Jawaharlal Nehru University Students Union (JNUSU), leader of the Students Federation of India (SFI)	19.02.2018
8	Bhagirath Choudhary	Founder Director at South Asia Biotechnology Center (SABC)	21.02.2018
9	B.N. Choudary	Bharatiya Kisan Sangh (BKS, "Indian Peasants' Union"; partner organization of RSS)	22.02.2018
10	Dr. Shivendra Bajaj	Executive Director of the Association of the Biotech Led Enterprises-Agriculture Focus Group (ABLE-AG) from DuPont Pioneer National Biotech Regulatory Cooperation Lead and China and Asia Pacific Regulatory Science And Operations Lead, Regulatory Manager Monsanto India Limited	23.02.2018
11	Jairam Ramesh	Minister of State (Independent Charge) for Environment and Forestry (2009-2011); member of the International Advisory Board (IAB) of International Environmental Technology Centre (IETC), UNEP; Congress Party of India (CPI)	23.02.2018
12	Dr. Suman Sahai	Founder of Gene Campaign	26.02.2018
13	Dr. G. V. Ramanjaneyulu	Executive Director, Centre for Sustainable Agriculture (CSA)	02.03.2018