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Organisational challenges for local maize value chains in the biobased economy

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Summary

The general objective of this dissertation is to generate key insights to address organisational challenges of local biomass value chains in the context of the biobased economy.

Several societal challenges, of which the most important is probably climate change, drive the increased interest to transform our fossil resources based economy into a biobased economy. Research aiming to enhance this transformation often focuses on the technical and techno-economic aspects of converting biomass into value-added products, but often fails to take into account the non-technical aspects, especially the organisational challenges related to local biomass value chains. These organisational challenges originate from the unique characteristics of both the biomass itself, such as low bulk density and seasonality, and the unique characteristics of the economic agents involved in the value chain, such as the wide dispersion of the producers. In order to gain insights in these challenges, we apply a complex adaptive systems lens and use a mixed-method approach, including semi-structured interviews and agent-based modelling. We focus on local value chains of maize, and divide our research into four specific case studies.

In the first case study, we investigate the already existing silage maize market and the competition for this locally traded biomass source between farmers and biogas plant managers in Flanders, the northern region of Belgium. We analyse the relative importance of contextual factors that contribute to the difficulty of obtaining a stable and affordable supply of silage maize by biogas plant managers. We find that the late entry of the biogas plant managers in the established market has a significant influence on the price volatility and increases silage maize prices for the farmers, especially if competition is fierce. Moreover, we find that the use of different institutional arrangements, such as building up long-term trust relationships, hardly affects the silage maize prices, nor the price volatility.

In the second case study, we investigate the influence of competition for corn stover on the development of a new corn stover value chain. We find that the presence of a large-scale centralized processor stimulates the development of a corn stover value chain, compared to when only small-scale decentralized processors are present. However, we conclude that under a spot market governance structure, there is little potential for a corn stover value chain in Flanders, as farmers' participation rate and hence corn stover supply is largely fluctuating, making investments too risky for curstim harvesters and processors.

In the third case study, we investigate the influence of governance structure on the development of a new corn stover value chain. We find that there is limited potential for a corn stover value chain when corn stover is directly traded between the farmers and the processor.

Also, when custom harvesters act as middlemen between the farmers and processors, there is a limited potential, because it leads to a largely fluctuating corn stover supply to the processor. A corn stover value chain under a cooperative governance structure has more potential, as corn stover supply is more stable. Nevertheless, the amount of stover that is supplied to the processor remains limited. Therefore, we conclude that a corn stover value chain in Flanders is preferable directed towards the creation of high value products, which can be produced in smaller-scale processes. For large-scale processes, feedstock flexibility has to be ensured.

In the final case study, we investigate how the process of new local biomass value chain development can be governed. Therefore, we compare two in-depth cases of attempts to develop a corn stover value chain. The first case considers the corn stover value chain in Ontario, Canada, which has been successfully developed. The second case considers the development of a corn stover value chain in Flanders, which remained unsuccessful up to now. Applying the integrated analytical framework described by Lamprinopoulou *et al.* (2014), we are able to deduce four factors that help in governing the development of new local biomass value chains: (1) determine the goal of the value chain; (2) consider the whole value chain and actively involve all stakeholders; (3) create trust and excitement amongst all stakeholders; and (4) obtain funding at the right point in time.

The insights gained from these four case studies guide us in answering three general research questions:

(1) To what extent is a complex adaptive system lens suitable to study local local biomass value chains for the biobased economy, taking into account their specific characteristics and those of its actors?
(2) How can the use of a mixed-method approach, comprising semi-structured interviews and agent-based modelling help in examining the mechanisms that drive the organisational challenges of local biomass value chains in the context of the biobased economy?
(3) What are the mechanisms behind the organisational challenges of local biomass value chains in the context of the biobased economy and how can they be addressed?

First, we evaluate to what extent local biomass value chains can be considered as CAS. After analysing the four case studies, we find that local biomass value chains are indeed characterised by the four properties (aggregation, non-linearity, flows and diversity) and can be described by the three mechanisms (tagging, internal models, and building blocks) common to all CAS. Hence, we conclude CAS theory provides a suitable lens to investigate organisational challenges for local biomass value chains in the biobased economy.

Next, we evaluate how the use of a mixed-method approach, comprising semi-structured interviews and agent-based modelling, can help in examining the mechanisms that drive the organisational challenges of local biomass value chains in the context of the biobased economy. We conclude that using a combination of semi-structured interviews and agent-based modelling, and especially the interplay between this qualitative and quantitative approach, allows us to yield better understanding of the different mechanisms that contribute to the organisational challenges of local biomass value chains. The interplay between the two methods presents itself in three ways. First, insights gained from semi-structured interviews provide a solid basis to identify the most important economic agents in the value chain and to formulate their behavioural rules. Second, insights gained from scenario analysis using agent-based modelling allow us to assess the relative contribution of the different contextual factors influencing local silage maize prices, price volatility and supply for biogas plant managers. Furthermore, they help us to identify the drivers and challenges associated with developing a corn stover value chain. As such, agent-based modelling helps to gain deeper understanding of the findings from the semi-structured interviews. Finally, after acquiring this more profound understanding, going back to the semi-structured interviews and conducting additional semi-structured interviews, helps us to derive strategies to address the organisational challenges identified and to further contextualize our findings.

Given the CAS lens and using the proposed mixed-method approach, we are able to identify three organisational challenges of local biomass value chains for new applications in the context of a biobased economy. First, we find that new entrants in well-established biomass value chains for competing applications, might have difficulties to obtain a stable and affordable supply of local biomass for their new applications in the context of the biobased economy. Secondly, also when new biomass value chains are established for new applications in the context of the biobased economy, processors risk to be confronted with an insecure input supply. Thirdly, we become aware of a lack of financial support to develop new biomass value chains for new applications in the context of the biobased economy. We are able to generate several key insights to address these challenges, which is also the main research objective of this dissertation. We formulate five recommendations for practitioners:

(1) Working with intermediaries is recommended as a way to mitigate the negative effects of a late entry into an already existing local biomass market. Working with intermediaries can somehow “undo” this late entry and reduce transaction costs.
(2) Keeping an adequate level of flexibility is recommended for all stakeholders involved in the value chain. Farmers can keep flexibility by planting multiple-purpose varieties or crops, custom harvesters can keep flexibility by investing in equipment that can be used to harvest multiple crops throughout the year, and processors can keep flexibility by designing the

processing plant in a way that it can process multiple feedstock types. Finally, also researchers and value chain developers should be flexible and willing to adjust their initial plans when developing new value chains. For example, when feedstock risks are considered too high, other valorisation trajectories could be considered.

(3) Making a well-considered choice about governance structure, reflecting the aspirations of the different economic agents involved in the value chain, increases the chance that these agents will actually participate and therefore the potential of the new value chain developed.

(4) In developing new value chains, one needs to make sure all stakeholders are involved. Forgetting one stakeholder can hamper the development of the whole value chain. While lots of research has been conducted on farmers' willingness to participate in biobased economy value chains, our research demonstrates that the other stakeholders also play a role. For example, we find that if custom harvesters are not willing to invest in the necessary harvesting equipment, the stover cannot be harvested and value chain development is hampered.

(5) Finally, when developing new local biomass value chains for new applications in the context of the biobased economy, we recommend practitioners to pay special attention to create trust and excitement for the new value chain amongst all stakeholders involved. This can be realized by organizing focus groups, harvest demonstrations, and/or technology-demonstrations. Furthermore, research results, including risks, should be honestly and openly communicated and discussed. Also, it is advisable to involve policy makers from the start of the value chain development.

Finally, we formulate two recommendations for policy makers:

(1) If the biobased economy is to become successful, not only technical or techno-economic research projects should be supported, but funds may also be necessary for projects that take a value chain approach. In such projects, knowledge of both researchers and practitioners should be brought together. This can be realized by the establishment of a kind of advisory committee, involving producers, custom harvesters, representatives from industry, representatives from civil society and policy makers, guided by a proficient boundary spanning actor.

(2) Because an uncertain subsidy environment is detrimental to attract investments for the biobased economy, we advise policy makers to move away from operational subsidies, which can often not be guaranteed over the long term, and go for investment and value chain development subsidies instead. Such subsidies can for example be provided in the form of tax allowances for investments in new biobased economy projects, tax reductions on the interests gained from investments in biobased economu projects, governmental investment credits with low interest rates, or investment subsidies.

Nederlandstalige samenvatting

Dit doctoraat heeft als doelstelling inzichten te genereren om organisatorische uitdagingen van lokale biomassa waardeketens in de context van de biogebaseerde economie te kunnen aanpakken.

Verschillende maatschappelijke uitdagingen, waarvan wellicht de klimaatsverandering de belangrijkste is, leiden tot een toegenomen interesse om onze economie gebaseerd op fossiele grondstoffen te transformeren naar een biogebaseerde economie. Onderzoek gericht om deze transformatie te vergemakkelijken focust vaak op de technische en techno-economische aspecten om biomassa in waardevolle producten om te zetten, maar vergeet daarbij vaak om ook de niet-technische aspecten in rekening te brengen, meer bepaald de organisatorische uitdagingen gelinkt aan lokale biomassa waardeketens. Inderdaad, gezien de unieke eigenschappen van biomassa, zoals lage bulkdichtheid en de seizoens-gebondenheid, en de die van de economische actoren van de waardeketen, zoals de wijde verspreiding van de producenten, worden lokale biomassa waardeketens in de context van de economie geconfronteerd met verscheidene organisatorische uitdagingen. Om inzichten te verwerven in organisatorische uitdagingen passen we complex adaptief systeemlens toe door middel van een "*mixed-method*" aanpak, bestaande uit semigestructureerde interviews en agent-gebaseerd modelleren. Om ons onderzoek meer te specifiëren, focussen we op de lokale maïs waardeketens, dewelke we opsplitsen in vier specifieke gevalstudies.

In de eerste gevalstudie onderzoeken we de reeds bestaande kuilmaïs market en de competitie tussen landbouwers en managers van een biogasinstallatie voor deze lokaal verhandelde bron van biomassa. Het onderzoek helpt ons om inzichten te verwerven in de contextuele factoren die bijdragen tot het moeilijk verkrijgen van een stabiele en betaalbare bron van kuilmaïs door managers van biogasinstallaties en om het relatieve belang van deze factoren te onderzoeken. We stellen vast dat de laattijdige intrede van de managers van biogasinstallaties een grote invloed heeft op de volatiliteit van de prijzen en ook de kuilmaïsprijzen opdrijft, zeker in het geval van hevige concurrentie. Verder, en min of meer onverwacht, vinden we dat het gebruik van andere institutionele arrangementen, zoals het opbouwen van vertrouwensrelaties op lange termijn, bijna geen effect heeft op de kuilmaïsprijzen, noch op de prijsvolatiliteit.

In de tweede gevalstudie onderzoeken we de invloed van competitie op de ontwikkeling van een nieuwe maïsstro-waardeketen. Onze resultaten tonen dat de aanwezigheid van een grootschalige, centraal gelegen verwerker de ontwikkeling van een maïsstro-waardeketen bevorderd. Echter, we concluderen ook dat wanneer maïsstro verhandeld wordt in een spotmarkt structuur, de kansen voor een succesvolle maïsstro-waardeketen beperkt zijn, omdat de deelname van de landbouwers erg fluctueert, en hierdoor ook het maïsstro-aanbod, wat maakt dat investeringen erg risicovol zijn.

In de derde gevalstudie onderzoeken we de invloed van de marktorganisatiestructuur op de ontwikkeling van een nieuwe maïsstro-waardeketen. We vinden dat de kansen voor een succesvolle maïsstro-waardeketen beperkt zijn wanneer maïs rechtstreeks wordt verhandeld tussen de landbouwers en de verwerker, of wanneer loonwerkers optreden als tussenfiguur, omwille van het enorm fluctuerende maïsstro-aanbod. Wanneer er een coöperatieve marktorganisatiestructuur wordt opgezet heeft de maïsstro-waardeketen een grotere kans op slagen, omwille van het meer stabiele maïsstro-aanbod. Echter, gezien het beperkte maïsstro-aanbod, concluderen we dat een maïsstro-waardeketen in Vlaanderen zich bij voorkeur moet richten op het produceren van hoogwaardige producten, die op een kleinere schaal kunnen worden geproduceerd, of om een zeker flexibiliteit te voorzien in de gebruikte biomassabronnen.

In de laatste gevalstudie onderzoeken we hoe nieuwe lokale biomassa-waardeketens kunnen worden ontwikkeld. Hiervoor vergelijken we twee diepgaande studies van voorbeelden van pogingen om een maïsstro-waardeketen te ontwikkelen. Het eerste voorbeeld is de succesvolle ontwikkeling van een maïsstro-waardeketen in Ontario, Canada. Het tweede voorbeeld is de ontwikkeling van een maïsstro-waardeketen in Vlaanderen, waarvan de pogingen onsuccesvol bleven tot nu toe. Het vergelijken van deze twee voorbeelden door het geïntegreerde analytisch kader beschreven door Lamprinopoulou *et al.* (2014) laat ons toe vier factoren te identificeren die helpen in het ontwikkelen van nieuwe waardeketens: (1) bepaal het doel van de waardeketen; (2) neem de hele waardeketen mee en betrek alle actoren bij het proces; (3) creëer vertrouwen en enthousiasme bij alle actoren; and (4) financiering op de juiste momenten. Tot slot toont deze studie het belang van waardeketen-denken aan.

De inzichten verkregen van deze vier gevalstudies helpen ons bij het beantwoorden van de algemene onderzoeksvragen.

(1) In hoeverre is een complex adaptief systeemlens geschikt voor het onderzoeken van lokale biomassawaardeketens voor de biogebaseerde economie, rekening houdend met hun specifieke kenmerken en die van de economische actoren?
(2) Hoe kan het gebruik van een *mixed-method* aanpak, bestaande uit semigestructureerde interviews en agent-gebaseerd modelleren helpen om de mechanismen te bestuderen die leiden tot de organisatorische uitdagingen van lokale biomassawaardeketens in de context van de biogebaseerde economie?

(3) Wat zijn de mechanismen achter de organisatorische uitdagingen van lokale biomassawaardeketens in de context van de biogebaseerde economie, en hoe kunnen deze worden aangepakt?

Eerst evalueren we in hoeverre de complex adaptief systeemlens die wordt gebruikt geschikt is om inzichten te verwerven in organisatorische uitdagingen van lokale biomassa waardeketens. Na het analyseren van de vier gevalstudies kunnen we besluiten dat lokale biomassa waardeketens inderdaad kunnen worden gekarakteriseerd door de vier eigenschappen (aggregatie, niet-lineariteit, stromen en diversiteit) en kunnen worden beschreven door de drie mechanismen (merken, interne modellen, en bouwstenen) die gemeenschappelijk zijn voor alle complex adaptieve systemen. Bijgevolg besluiten we dat de CAS-theorie een goede lens biedt om organisatorische uitdagingen voor lokale biomassa-waardeketens in de context van de biogebaseerde economie te bestuderen.

Vervolgens evalueren we of de mixed-method aanpak geschikt is om organisatorische uitdagingen van biomassa-waardeketens te onderzoeken. We concluderen dat het gebruik van de combinatie van semigestructureerde interviews en agent-gebaseerd modelleren, en vooral dan de wisselwerking tussen deze kwalitatieve en kwantitatieve methode, ons toelaat om de mechanismen die bijdragen tot de organisatorische uitdagingen van biomassa-waardeketens beter te begrijpen. Deze wisselwerking komt op de volgende drie manieren tot uiting. Eerst, inzichten verkregen uit de semigestructureerde interviews vormen een goede basis om de belangrijkste economische actoren te identificeren en om hun gedragsregels te formuleren. Ten tweede, inzichten van de scenario-analyse met behulp van de agent-gebaseerde modellen helpen in het evalueren van de relatieve bijdrage va de verschillende contextuele factoren die de prijzen van lokaal verhandelde kuilmaïs beïnvloeden, alsook de prijsvolatiliteit en het aanbod voor de managers van biogasinstallaties. Ook helpen de resultaten van de agent-gebaseerde modellen ons de belangrijkste stimulansen en uitdagingen voor het ontwikkelen van een maïsstro-waardeketen te identificeren. We kunnen dus stellen dat agent-gebaseerd modelleren ons helpt om een diepgaander inzicht te verwerven in de bevindingen van de semigestructureerde interviews. Ten slotte, nadat dit diepgaander inzicht werd verworden, kunnen strategieën ontwikkeld worden om de organisatorische uitdagingen aan te pakken en kunnen de resultaten meer in hun context worden geplaatst, door terug te gaan naar de semigestructureerde interviews en door nieuwe interviews af te nemen.

Gegeven de complex adaptief systeemlens en door het gebruik van de *mixed-method* aanpak, kunnen we organisatorische uitdagingen van lokale biomassa-waardeketens in de context van de biogebaseerde economie identificeren. Ten eerste vinden we dat nieuwe spelers die een goed georganiseerde biomassa-waardeketen binnenkomen voor gebruik in een competitieve toepassing, moeilijkheden kunnen ondervinden om een stabiele en betaalbare toevoer van locale biomassa te kunnen verkrijgen voor nieuwe toepassingen in the context van de biogebaseerde economie. Ten tweede, ook wanneer nieuwe biomassa-waardeketens worden ontwikkeld voor nieuwe toepassingen in de context van de biogebaseerde economie, kunnen verwerkers geconfornteerd worden met een onzekere biomassa-toevoer. Ten derde ondervinden we de moeilijkheid om financiële steun te vinden voor het ontwikkelen van nieuwe biomassa-waardeketens voor nieuwe toepassingen in de context van de biogebaseerde economie. Bovendien kunnen we belangrijke inzichten verwerven om deze uitdagingen aan te pakken, wat ook het algemene onderzoeksdoel is van dit doctoraat. We formuleren vijf praktische aanbevelingen voor stakeholders uit de praktijk:

(1) Het samenwerken met tussenpersonen is aangeraden als een manier om de negatieve effecten van een late intrede in een reeds bestaande lokale biomassamarkt, zoals een hogere prijsvolatiliteit, te beperken. Werken met tussenpersonen kan op een bepaalde manier de late intrede “ongedaan maken” en daarenboven ook de transactiekosten verminderen.

(2) Het behouden van een voldoende grote flexibiliteit is aangeraden voor alle stakeholders van de waardeketens. Landbouwers kunnen hun flexibiliteit behouden door meer-doelen-rassen of –gewassen te planten, loonwerkers kunnen hun flexibiliteit behouden door te investeren in machines die meerdere gewassen kunnen oogsten doorheen het jaar, en verwerkers kunnen hun flexibiliteit behouden door het verwerkingsproces zo op te stellen dat het meerdere biomassasoorten kan verwerken. Ten slotte moeten ook onderzoekers en ontwikkelaars van waardeketens flexibel zijn wanneer ze nieuwe waardeketens willen ontwikkelen. Dit kan bijvoorbeeld door de grootte van de verwerkingsfabriek aan te passen, of door nieuwe stakeholders bij het proces te betrekken indien nodig.

(3) Het maken van een weldoordachte keuze wat betreft de marktorganisatiestructuur wordt ook aangeraden. Deze structuur moet zo goed mogelijk de wensen van de verschillende economische actoren reflecteren om de kans te vergroten dat deze actoren ook werkelijk zullen deelnemen aan de waardeketen en de kans te vergroten dat de nieuwe waardeketen succesvol wordt.

(4) Wanneer nieuwe waardeketens worden ontwikkeld is het belangrijk dat alle actoren worden meegenomen. Het vergeten meenemen van één stakeholder kan ertoe leiden dat het ontwikkelen van de hele waardeketen wordt verhinderd. Terwijl veel onderzoek gedaan wordt naar de interesse van landbouwers om deel te nemen aan waardeketens voor de biogebaseerde economie, tonen we aan in ons onderzoek dat ook de andere stakeholders een rol spelen. Bijvoorbeeld, we tonen aan dat als loonwerkers niet willen

investeren in de nodige oogstmachines, maïsstro niet kan geoogst worden en het ontwikkelen van de waardeketen wordt gehinderd.

(5) Ten slotte, wanneer nieuwe lokale biomassa-waardeketens voor de biogebaseerde economie worden ontwikkeld, raden we aan om ook aandacht te besteden aan het creëren van vertrouwen en enthousiasme voor de nieuwe waardeketen die wordt ontwikkeld. Dit kan worden gerealiseerd door het organiseren van focusgroepen, oogstdemonstraties, en/of technologiedemonstraties. Daarenboven is het belangrijk om de onderzoeksresultaten, waaronder ook de risico's, eerlijk en openlijk te communiceren en te bediscussiëren. Bovendien wordt het aangeraden om ook beleidsmakers vanaf het begin te betrekken bij het ontwikkelen van nieuwe waardeketens.

Ten slotte formuleren we ook twee aanbevelingen voor beleidsmakers:

(1) Om de biogebaseerde economie succesvol te maken, moeten niet enkel technische en techno-economische onderzoeksprojecten moeten worden ondersteund, maar we raden beleidsmakers aan om specifieke fondsen opzij te zetten voor projecten die een waardeketenaanpak hanteren. In zulke projecten zou zowel de kennis van wetenschappers als van personen uit de praktijk moeten worden samengebracht. Dit kan worden gerealiseerd door het opzetten van een soort adviesgroep, waarin landbouwers, loonwerkers, vertegenwoordigers uit de industrie, vertegenwoordigers van belangengroepen en beleidsmakers zetelen. Zo'n adviesgroep zou dan moeten worden begeleid door een bekwame tussenpersoon (*boundary spanner*).

(2) Aangezien een onzeker subsidiebeleid nefast is om nieuwe investeringen voor de biogebaseerde economie aan te trekken, raden we beleidsmakers aan om operationele subsidies, die vaak niet kunnen worden gegarandeerd op lange termijn, af te bouwen en in de plaats meer in te zetten op subsidies die waardeketenontwikkeling ondersteunen. Zulke subsidies kunnen bijvoorbeeld worden toegekend in de vorm van belastingaftrekmogelijkheden voor investeringen in nieuwe projecten voor de biogebaseerde economie, belastingvermindering op de interesten die worden gewonnen uit investeringen in projecten in de biogabaseerde economie, overheidsinvesteringskredieten met lage interesten, of investeringssubsidies.

List of abbreviations

ABM	Agent-Based Model
AGM	Actual Gross Margin
BBEU	BioBase Europe Pilot Plant
BIC	Bioindustrial Innovation Canada
CAD	Canadian Dollar
CAP	Common Agricultural Policy
CAS	Complex Adaptive System
CH	Custom Harvesters
CSPC	Cellulosic Sugar Producers Co-operative
CSPP	Cellulosic Sugar Production Plant
DM	Dry Matter
DVE	Darm Verteerbaar Eiwit
EC	European Commission
EIP-Agri	Agrlcultural European Innovation Partnership
ETIP	European Technology and Innovation Platform
EU	European Union
FADN	Farm Accountancy Data Network
IBO	InterBranch Organisation
IGPC	Integrated Grain Processors Co-operative
IPCC	Intergovernmental Panel on Climate Change
ODD	Overview Design and Details
OECD	Organisation for Economic Cooperation and Development
OFA	Ontario Federation of Agriculture
PGM	Potential Gross Margin
PO	Producers Organisation
SALV	Strategic Advisory Board for Agriculture and Fisheries
SOC	Soil Organic Carbon
VEM	VoederEenheid Melk
WTA	Willingness To Accept
WTP	Willingness To Pay

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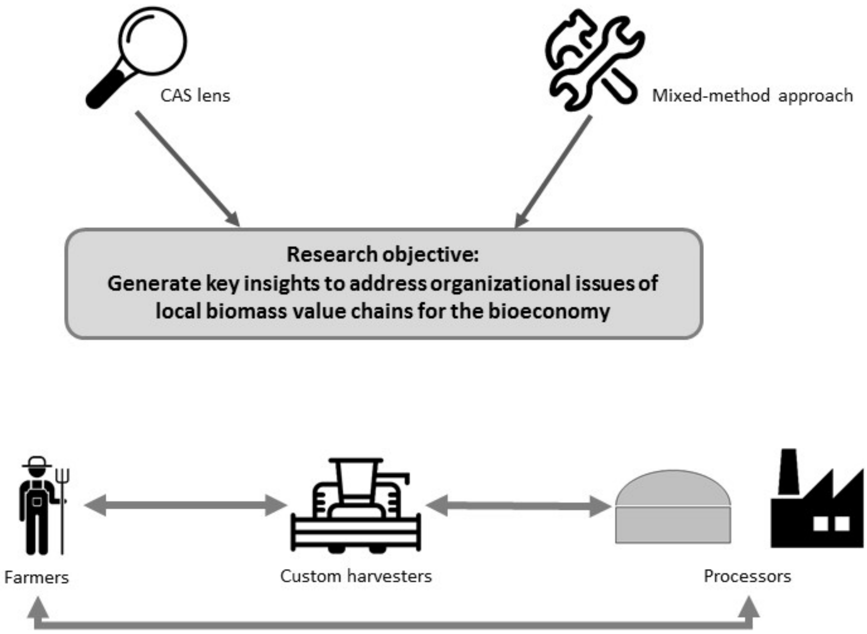
Chapter 1: Introduction



Preface

The general objective of this dissertation is to generate key insights to address organisational challenges of local biomass value chains in the context of the biobased economy.

Several societal challenges, of which the most important is probably climate change, drive the increased interest to transform our fossil resources based economy into a biobased economy. Research aiming to enhance this biobased economy often focuses on the technical and techno-economic aspects of converting biomass into value-added products, but often fails to take into account the non-technical aspects, especially the organisational challenges related to local biomass value chains. In this dissertation, we present research aiming to identify these challenges. We look at the issue with a complex adaptive systems lens and use a mixed-method approach, combining semi-structured interviews and agent-based modelling.

We focus on the case of local value chains of maize and divide our research into four specific case studies. Each of these case studies allows us to answer one specific research question, which then guides us in providing an answer to three general research questions.

In this introduction, we will discuss the need for the further development of the bioeconomy and biobased economy and the unique characteristics of biomass value chains. Furthermore, we argue the need to also study organisational challenges of local biomass value chains in this context, besides studying technical and techno-economic studies. Finally, we present our research approach and introduce the case of local maize value chains.

1.1 The need for a biobased economy

The terms “bioeconomy” and “biobased economy” are increasingly being recommended in scientific literature and policy documents as a way to move away from a fossil based economy. The European Commission (EC) defines the bioeconomy as “the production of renewable biological resources and the conversion of these resources and waste streams into value added products, such as food, feed, biobased products and bioenergy. The bioeconomy includes the sectors of agriculture, forestry, fisheries and pulp and paper production, as well as parts of chemical, biotechnological and energy industries” (European Commission 2012a). Over time, other authors and institutions have also given their own definition and interpretation of the terms ”bioeconomy”, or “knowledge-based bioeconomy” (Golembiewski et al. 2015). These terms are often used interchangeably and their definitions range from a mere technical interpretation, focusing on the role of biotechnology, over a bioresource vision, focusing on the use of biomass and the development of new value chains, to a bioecology vision, focusing on the sustainability and ecological aspects of the bioeconomy (Bugge et al. 2016). More specifically, the term “biobased economy” was introduced ro refer to that section of the bioeconomy in which biomass is used for the production of energy and materials (Uyttendaele et al. 2013). Whatever the definition or focus, some aspects always recur (McCormick & Kautto 2013; Van Lancker 2017). The most important aspect for this dissertation is the use of biomass instead of fossil fuels for the production of value-added products. More specifically, we focus on the use of local biomass resources for new applications in the context of the biobased economy, namely for biomaterials and bioenergy purposes. Additionally, although not explicitly part of the definition of the biobased economy, we take a value chain perspective, and therefore also take into account the biomass production process.

Various reasons lie behind the increased interest in the bioeconomy and biobased economy. As stated by several authors (Asveld et al. 2011; Sanders & van der Hoeven 2008), probably the most important driver for a biobased economy is climate change. Due to emissions of greenhouse gases, including carbon dioxide (CO_2) and methane (CH_4), global temperatures are rising. According to the Intergovernmental Panel on Climate Change (IPCC), we need to cut greenhouse gas emissions from 41% to 72% by 2050 compared to 2010, in order to avoid a temperature rise of more than 2°Celcius (C) (IPCC 2014). The transition to a sustainable biobased economy could contribute to this, because the processing of biomass would not emit more CO_2 than is taken up during its growth (Manshoven et al. 2012; Asveld et al. 2011). The prediction of "peak oil" is another reason for the increased interest. This is the prediction that "oil production would peak when about half of the economic recoverable resource has been exploited" (Kharecha & Hansen 2008, p.1). Apart from the discussion on whether or not we have already reached peak oil (Höök & Tang 2013; Kharecha & Hansen 2008), the concept makes clear that fossil fuels will not be at our disposal forever. In this regard, the use of biomass instead of fossil fuels to produce energy and materials could lower our dependency on diminishing fossil resource stocks, which originate from just a few countries (European Commission 2012a; Manshoven et al. 2012; Wille 2012; Asveld et al. 2011; Vandermeulen et al. 2010; Sanders & van der Hoeven 2008). Instead, in a biobased economy, we could become more self-sufficient in terms of resource provision (Wille 2012). Moreover, the establishment of a biobased economy could contribute to economic growth, by generating sustainable jobs in both rural and urban environments (European Commission 2012a) and creating new value chains for agricultural products, thereby providing additional income for farmers (McCormick & Kautto 2013). Furthermore, while the biobased economy is often perceived as a possible threat to food security (Frow et al. 2009), it also has the potential to improve food security, because it encourages the further development of knowledge about the sustainable production of primary products (European Commission 2012a). Finally, and more overarching, a biobased economy could help us to create a more sustainable society and economic system (Wille 2012).

1.2 Challenges for the further development of the biobased economy

Substantial volumes of biomass are already circulating in our economy. The European Commission estimated that between 1600 and 2200 million tonnes of biomass are produced in the European Union (EU), of which at least 20% remains unused. Furthermore, the bioeconomy in its broadest sense has a turnover of about 2 trillion euros and already employs more than 17 million people. A large majority of the biomass, 61%, is currently used for the production of animal feed and food (Ronzon et al. 2015). About 18% of the biomass is used for the production of biomaterials and another 18% for the production of bioenergy (Ronzon et al. 2015). Hence, the further development of the biobased economy would certainly not be starting from scratch.

Nevertheless, the development of the biobased economy still faces some challenges. To meet some of these challenges, extensive research has been conducted over recent decades on improving existing techniques or introducing new and more efficient ways of harvesting, transporting and processing biomass for biomaterials and bioenergy. Although these technical studies have proven their worth, much less attention has been devoted to the non-technical challenges associated with the use of local biomass for new applications within the context of the biobased economy. These non-technical barriers are described by Costello and Finnell (1998) and Rösch and Kaltschmitt (1999) for the specific case of the bioenergy sector. They are grouped into four categories:

- financial challenges, relating to project financing, public funding and subsidies and investment risks;
- perceptual challenges, relating to the knowledge and perception of the public, policy makers and corporate decision makers in the bioenergy sector;
- regulatory challenges, relating to specific policies and regulations that either give an incentive to the bioeconomy and biobased economy or hamper its development; and
- infrastructural and organisational challenges, relating to the organisation of the biomass value chain.

These challenges have already been analysed for the bioenergy sector, but they should also apply to other new applications of biomass within the biobased economy. In this dissertation, we focus on the last category of challenges, namely the infrastructural and organisational challenges. More in particular, we focus on the organisational aspects of local biomass value chains for new applications within the biobased economy. Indeed, "efficient and equitable markets for biomass" are considered fundamental for the further development of the biobased economy and commercialization of new or improved technologies might even be hampered if organisational issues are not properly addressed (Altman et al. 2013). Nevertheless, very little research has been conducted on the organisational aspects and challenges relating to biomass value chains within the context of new applications within the biobased economy (Altman et al. 2007; Golembiewski et al. 2015; Van Lancker et al. 2016). However, before we can investigate these organisational challenges, we first need to understand the concept of a value chain and, more specificially clarify the unique characteristics of the biomass value chains. This is discussed in the next section.

1.3 Biomass value chains

Value chains are defined as a “set of interdependent economic activities”, which are undertaken by “a group of vertically linked economic agents” (Bellù 2013, p.3). The economic activities in biomass value chains usually include biomass production, either purposely grown or as a residue, biomass harvesting and collection, storage, transport and processing (Iakovou et al. 2010; Awudu & Zhang 2012). Actors, or economic agents, involved in these activities include for example farmers, custom harvesters, and processors. These economic agents should be vertically linked. This can be realized by formal contracts, informal agreements or other governance structures. Hence, in this dissertation, we will focus on how these vertical links can be organised in order to obtain successful local biomass value chains for new applications within the biobased economy.

Biomass value chains within the context of the biobased economy are different from other value chains because of some unique characteristics of biomass. Firstly, although biomass supply for the biobased economy is often taken for granted, it is not abundantly available, which sometimes complicates year-round operation of processing plants. If sufficient biomass is available, large storage areas are often needed, because of the seasonal character of most biomass sources (Rentizelas et al. 2009; De Meyer 2015; Iakovou et al. 2010; Shabani et al. 2013). Additionally, when dealing with seasonally available biomass, collection time is limited, so the use of equipment and workforce is concentrated on a particular time, sometimes leading to the inefficient use of resources (Rentizelas et al. 2009). Also, some biomass sources require customized equipment for collection and handling, which further complicates the structure of the value chain (Rentizelas et al. 2009). Finally, biomass sources generally have low bulk density and high moisture content, leading to high collection, handling and transportation costs (Rentizelas et al. 2009; De Meyer 2015; Gold & Seuring 2011; Shabani et al. 2013).

Besides these unique characteristics of the biomass itself, local biomass value chains for applictions within the biobased economy are also influenced by the characteristics of the economic agents involved. Indeed, biomass value chains are often characterized by a large number of producers dispersed within the collection area of a relatively small number of processors, further increasing transportation and handling costs (De Meyer 2015; Shabani et al. 2013; Iakovou et al. 2010). Therefore, biomass supply chains are usually very local, having a typical 80 to 100 kilometre (km) radius of collection (Costello & Finnell 1998). Moreover, due to its geographical dispersion and the many actors involved with its production, entirely new input procurement procedures are needed, which require the development of many new vital relationships (Altman & Johnson 2008), when setting up new value chains within the context of the biobased economy. Often, the processors enter existing biomass value chains that are part of the wider bioeconomy, in which biomass is traded through barter or informal contracts between crop farmers and livestock producers (Altman & Johnson 2008). In this context, biomass producers are usually driven not only by rational economic goals, but they also operate within a context and network of other economic agents to which they might have a sense of loyalty. Also, other social aspects including lifestyle satisfaction or nature conservation may play a role (Higgins et al. 2009). Furthermore, in bioenergy or biomaterials value chains, large biomass conversion facilities require a continuous supply of biomass of sufficient quality over a time span of multiple years (Iakovou et al. 2010). As such, stable relationships with the many biomass suppliers are crucial for the further development of the biobased economy (Gold 2010). However, as the biomass sector is characterized by a highly variable economic environment because of fluctuations in fossil fuel prices, and changing agronomic conditions and technological factors, it is challenging, if not impossible to create contracts that prevent the possibility of opportunistic behaviour when the opportunity arises to enter into new relationships (Altman et al. 2007).

As a result of these unique characteristics of both biomass itself and the economic agents involved in biomass value chains, establishing a biobased economy will take more than the mere introduction of new or advanced technologies (Wille 2012). Indeed, the organisational aspects of local biomass value chains for bioenergy or biomaterial purposes also need to be addressed, by taking into account the individual decisions taken by the different actors involved, their behaviour, as well as the institutional context in which they operate (Altman et al. 2013; Altman & Johnson 2008). This is further discussed in the next section.

1.4 Complex adaptive systems and their characteristics

In research, value chains and/or supply chains are often seen as single entities that can be managed in a coherent way by imposing strategies that are beneficial for the supply chain as a whole (Türkay et al. 2004; Kempener et al. 2009). However, as highlighted in the previous section, biomass value chains are made up of single agents, each of them having their own set of goals, following individual rules, and interacting with each other to exchange resources. These interactions are not "a linear chain of one-on-one business relationships", but merely an assemblage of different firms linked through different networks and relationships (Surana et al.

2005, p.4239). Therefore, to gain insights into the organisational aspects of biomass value chains, thereby taking into account the individual decisions taken by the different actors involved, as well as the institutional context in which they operate, a complex adaptive system (CAS) lens might be interesting.

Systems are considered to be complex if they are composed of interacting units and if they "exhibit emergent properties, that is, properties arising from the interactions of the units that are not properties of the individual units themselves" (Tesfatsion & Judd 2006, p.836). CAS are complex systems that include elements that are able to adapt to changes in their environment (Surana et al. 2005). Over time, authors have provided different definitions for CAS. For example, Holland (2006) describes CAS as "systems that have a large number of components, often called agents, that interact and adapt or learn" (Holland 2006, p.1). Tesfatsion and Judd (2006) gave the following three different definitions:

(1) "A complex adaptive system is a complex system that includes reactive units, i.e., units capable of exhibiting systematically different attributes in reaction to changed environmental conditions"
(2) "A complex adaptive system is a complex system that includes goal-directed units, i.e., units that are reactive and that direct at least some of their reactions towards the achievement of built-in (or evolved) goals."
(3) "A complex adaptive system is a complex system that includes planner units, i.e., units that are goal-directed and that attempt to exert some degree of control over their environment to facilitate achievement of these goals" (Tesfatsion & Judd 2006).

In his definition, Holland (2006) refers to agents that interact, adapt, or learn, but without purposely directing the system to a certain goal and without explicitly clarifying the drivers behind the interactions and adapting or learning behaviour. Conversely, the definitions provided by Tesfatsion and Judd (2006), explicitly include these drivers, with increasingly sophisticated behaviour regarding the adaptability and learning behaviour of the agents. The applicability of these definitions to describe local biomass value chains will be evaluated at the end of this dissertation.

According to Holland (1998), each complex adaptive system contains seven basic elements: four properties (aggregation, nonlinearity, flows, and diversity) and three mechanisms (tagging, internal models and building blocks). Below, we describe these basic elements as introduced in Holland (1998), unless indicated otherwise.

First, all CAS are characterized by aggregation, at least at a certain level. According to Holland (1998), aggregation can be interpreted in two ways. On the one hand, aggregation can be interpreted as a way to group agents in order to be able to include them in simulation models developed to answer certain research questions. In doing so, the characteristics of these agents, which are interesting for the purpose of answering the research question, are often exaggerated, while other – less interesting – characteristics are ignored. For example, we group actors that have land and grow crops as farmers. In doing so, we can ignore the colour of their hair or the number of children they have. The mechanism of grouping actors based on certain characteristics is called tagging, which is the first mechanism described by Holland (1998). It should be noted that in the models, each agent is still modelled individually, in order to allow for diversity in their characteristics. For example, while farmers are grouped as agents that have land and grow crops, they also differ from one another in the amount of land and the type of crops they grow. On the other hand, aggregation can be interpreted as the "emergence of complex large-scale behaviours" (Holland 1998, p.11), which are formed by the confluence of simple behaviours by the actors. In our case, this would be the emergence of a market or value chain with certain characteristics concerning supply, feedstock prices, etc.

Secondly, all CAS exhibit nonlinear behaviour. Choi *et al.* (2001) defined non-linear relationships as "relationships in which a change of given magnitude in the input to the system is not matched in a linear fashion to a corresponding change in output" (Choi et al. 2001, p.356). This means that the dynamics of the emergent phenomena cannot be described by linear equations. Instead, the confluence of the interactions of the different actors can lead to complex behaviour of the system that cannot be predicted by summing or averaging the individual actions of the agents. Examples of non-linear behaviours are, for example, sudden drops in prices or supply. Given these non-linearities, CAS are stated to be in a quasi-equilibrium state, with the potential for falling from complete order into complete disorder (Choi et al. 2001). Furthermore, feedback loops make the behaviour of the system even more complex, as correlations arise between the individual decision-making, interactions between the agents and the emergent phenomena and the environment (Kempener et al. 2009; Tesfatsion & Judd 2006; Pathak & Dilts 2002).

Thirdly, flows are common to all CAS. These can either be flows of goods, such as the trade of certain feedstock or flows of information. Flows usually run through networks of actors, in which the actors are linked to each other. Over time, these networks can evolve, when certain links are broken or new ones are formed.

Fourthly, while actors in a CAS can be aggregated into, for example, farmers, or processors (first property), they are also characterized by their heterogeneity or diversity. Indeed, by grouping all farmers and highlighting the fact that they have land, grow crops and have a certain location, we also highlight their differences. For example, one farmer can grow maize and wheat, while another grows maize, potatoes and has some permanent grassland. Actors also have different social characteristics. For example, some farmers are more risk averse than others, some like to copy the behaviour of other farmers, while some operate more as individuals. As a result of the whole of their characteristics (social and non-social), the actors can make decisions according to their internal model. Such an internal model is the second mechanism that is part of every CAS, and allows actors to make decisions in order to adapt to their environment. These internal models can be tacit or overt. Overt internal models take into account the possible outcomes of a decision. For example, if a farmer grows potatoes, he expects to be able to sell them at a certain price. In contrast, tacit internal models are merely a random-search and hit-and-miss mechanism, like ants randomly walking around before they find food. To construct internal models, we need building blocks, which is the third, and last, mechanism described by Holland (1998). Such building blocks can be simple if-then rules, for example, if the potatoes are ready, they need to be harvested.

Over the course of this PhD, we aim to find out whether or not value chains of locally produced biomass in the context of the biobased economy encompass these seven basic elements, and can therefore be considered as complex adaptive systems.

1.5 Objective and general research questions

The general objective of this dissertation is to explore **how value chains of local biomass for the biobased economy can be organized**. We only focus on the organisational aspects. As such, we do not explicitly investigate financial, technical or regulatory perspectives, but rely on the available knowledge and information described in the literature. In other words, what are the key insights needed that allow us to address organisational issues of local biomass value chains for the biobased economy, taking into account the the specific characteristics of biomass value chains and the actors involved? In order to achieve this objective, three general research questions need to be examined in more detail.

First, considering the specific characteristics of local biomass value chains and the actors involved, we need a specific angle to look at the organisational issues. Therefore, we put forward the following question:

General research question 1: To what extent is a complex adaptive system lens suitable to study local biomass value chains for the biobased economy, taking into account their specific characteristics and those of its actors?

Next, we need to assess how the proposed mixed-method approach, discussed below, helps in studying the organisational aspects of value chains of local biomass for the biobased economy, by formulating the following research question:

General research question 2: Given the CAS lens, how can the use of a mixed-method approach, comprising semi-structured interviews and agent-based modelling, help in examining the mechanisms that drive the organisational challenges associated with local biomass value chains in the context of a biobased economy?

Using the CAS lens and the mixed-method approach, we aim to identify organisational challenges of local biomass value chains and formulate recommendations to address them, by putting forward the following question:

General research question 3: Given the CAS lens and using the proposed mixed-method approach, what are mechanisms behind the organisational challenges associated with value chains for local biomass in the context of a biobased economy and how can these challenges be addressed?

As these general research questions may remain somewhat abstract, we will apply them to local value chains for maize. We define specific research questions, which will help us in answering the general research questions. At the end of this chapter, we detail how these specific research questions link into the general research questions and present the outline of this dissertation. However, before we formulate the specific research questions, we first present the research approach and provide some general background information on local maize value chains.

1.6 Research approach

Research methods used for studying the organisational issues associated with local biomass value chains for new applications in the biobased economy need to take into account the specific characteristics of biomass value chains and the actors involved, which we specified in sections 1.3 and 1.4. Indeed, insight is needed into the behaviour of the different actors in order to be able to investigate how the combination of the individual actors' behaviour and their interactions lead to emergent phenomena, namely the value chain with its specific characteristics. Therefore in this dissertation, we use a mixed-method approach, integrating a qualitative and a quantitative research method. According to Pluye and Hong (2014), a mixed-method approach is advantageous, as it "combines the strengths of the quantitative and qualitative methods and compensates for their respective limitations". In this PhD, we integrate a qualitative method, semi-structured interviews and their analysis, with a quantitative method, agent-based modelling (Pluye & Hong 2014). More concretely, we use a sequential exploratory mixed-method design (Pluye & Hong 2014), meaning that we first conducted and analysed the semi-structured interviews, to inform the agent-based models. Then the results of the agent-based models were interpreted and further helped to understand and confirm the findings from the semi-structured interviews (Pluye & Hong 2014). In the following sections, we further detail the two methods.

1.6.1 Semi-structured interviews

Before agent-based models could be developed, we needed a thorough knowledge of the different corn value chains in Flanders. As this knowledge is difficult and time consuming to obtain from the literature, we conducted several semi-structured interviews with different stakeholders. This type of interviewing is a useful way to acquire a large quantity of information in a limited amount of time (Bernard 2006), providing empirical knowledge and a level of understanding that often cannot be acquired through literature alone. The interviews helped us to understand the different behavioural rules of the economic agents and their interactions. As such, we had a good empirical basis to develop our agent-based models.

The semi-structured interviews were scheduled, following a “general script” and covering “a list of topics (Bernard 2006, p.210). Before the interview, an interview guide was produced, which served as a reminder during the interview itself. The interview guide ensured that no topics were forgotten, but it allowed the possibility for following new leads or changing the topic if deemed necessary (Bernard 2006). During the research process, the data were directly interpreted and further data collection was based on the previous collected knowledge. During each data collection round, interviewees were selected as follows. At first, semi-structured interviews were undertaken with experts, selected through a web search based on the organisation they represented and their specific knowledge on the subject. These experts could provide general insights in the subject investigated. Furthermore, these experts also provided names of other stakeholders involved, including farmers, custom harvesters and processors who, in turn, provided names of other stakeholders. Interviews with these respondents provided more detailed knowledge. When we believed that no further information could be acquired by conducting more interviews, the interview round was ended. In total, 56 interviews were conducted, spread over three interview rounds: two took place in Flanders, one in Ontario, Canada. Most interviews were conducted face-to-face. However, given some time limitations and long distances, some interviews were conducted using Skype. Table 1.1 gives an overview of the interviews conducted. We recorded and transcribed all the interviews and analysed them using NVIVO 11.

Table 1.1 Overview of interviews conducted. The symbol '#' stands for 'number of'

Period	Focus	# Respondents
July – September 2013	Explorative	6 (+1)[1]
December 2013 – August 2014	Trade of silage maize	14
March – September 2015	Potential of corn stover harvest in Flanders	14
August – September 2016	Developing a corn stover value chain in Ontario	21

1.6.2 Agent-based modelling

Once we had gained a clear understanding of the different actors involved in the value chains, their behavioural rules and their interactions, we could start developing several agent-based models. Agent-based modelling is a method that allows researchers to gain an understanding of the reasons behind certain emergent phenomena by conducting scenario analysis. In our case, agent-based models could help us to understand why certain value chains of local biomass have certain characteristics, such as price volatility, fluctuations in supply, farmers' participation in the value chains, etc.

More technically, agent-based modelling was defined by Gilbert (2008) as "a computational method that enables a researcher to create, analyse, and experiment with models composed of agents that interact within an environment" (Gilbert 2008, p.2). As can be deduced from the definition, agent-based modelling is a bottom-up modelling approach, departing from the individual agents who are part of a complex adaptive system, such as a biomass value chain. North and Macal (2007) define agents as the "decision making components in complex adaptive systems" (North & Macal 2007). In our case, the agents could be the farmers, the custom harvesters or the processors in the corn stover value chain. Each actor is given a set of attributes, which are, for example, the location of the farmer or the area he has at his disposal for cultivation. In an agent-based model (ABM), the agents interact with each other and with their environment. Here, interaction refers to transferring information, which can be both direct and indirect. Direct information is communicated one-to-one between agents, such as price offers or price requests. Indirect information is, for example, the observation of the behaviour of other agents and its effects (Gilbert 2008). Based on the information, the agents can act according to certain behavioural rules. Furthermore, an agent is able to learn from past experiences and to adjust his behaviour to achieve a certain goal, or "fitness", which is often profit maximization. The agents in an ABM interact and act within a virtual environment. If the environment is spatially explicit, each of the agents is attributed an x- and y-coordinate indicating his specific location in this environment (Gilbert 2008). Interactions and transactions between the agents then result from the behavioural rules and the modelled environment. From these interactions and transactions, a biomass value chain emerges.

[1] One interview was conducted in May 2015

ABMs have some interesting advantages. Firstly, agent-based modelling allows the heterogeneity of the agents to be taken into account; each agent is assigned individual parameter values at the start of the simulations and can follow different behavioural rules to make his choice. Secondly, real-world stakeholders can be directly included in the model as agents. For example, one can include farmers and processors. Also the environment in which the agents operate can be directly translated into the model code. This makes it easier to develop the model and to interpret its results, compared to equation-based models (Gilbert 2008). Moreover, ABMs can be used in cases where an analytical solution cannot be found (Gilbert 2008). Furthermore, agent-based modelling permits researchers to relax some assumptions often taken for granted in other models, such as economically rational behaviour or economic equilibria (Tesfatsion & Judd 2006; Gilbert 2008). Additionally, agent-based modelling allows the modeller to represent reality in a natural way (Tesfatsion & Judd 2006; Matthews et al. 2007; Happe 2004; Negahban & Yilmaz 2014; Kostadinov et al. 2013). Finally, ABMs are computational models, meaning that they are small computer programs that can execute simulations. Executing different simulations, with different initial values allows the researcher to conduct experiments and undertake a scenario analysis. As a result, ABMs can be used to systematically gain qualitative insights into economic systems, by sequentially testing different initial conditions (Tesfatsion & Judd 2006).

However, ABMs also have some disadvantages. Their main disadvantage is that they tend to become highly complex when they are designed to gain insight in real world phenomena. As such, the models are difficult to understand and may come across as a black-box model and therefore interpretation of the results is considered challenging for people outside of the research project (Waldherr & Wijermans 2013). Furthermore, in order to feed these models, input data need to be provided for the many parameters. However, as these data are often not available, the researcher is forced to make some assumptions (Yang & Gilbert 2008; Boero & Squazzoni 2005). Contrarily, when researchers decide to keep their models very simple, their agent-based models are often found to be too abstract or too far from reality and oversimplifying social processes (Waldherr & Wijermans 2013). The main challenge for researchers is therefore to find the right balance between increasing model complexity in order to represent reality, and keep the model simple enough to ensure its comprehensibility. In literature, this is referred to as finding the balance between descriptive accuracy and analytical tractability (Windrum et al. 2007). Furthermore, ABMs inherently are characterised by many coding lines, increasing the chance for errors in the modelling code (Gilbert 2008). As ABMs are bottom-up models, the researcher does not know in advance whether the complex adaptive system of study will arise from his simulations and what their characteristics would be. Therefore, it is often very difficult to detect these bugs (Galán et al. 2009). Finally, validation of ABM results is found challenging as the simulations are presented as distributions, which are difficult to compare with reported single time-series data (Tesfatsion & Judd 2006).

When designing ABMs and analysing their simulation results, it is important to keep these advantages and disadvantages in mind. In Chapter 6, we therefore further reflect on them, discussing how we experienced them during our research and how we dealt with them.

Different ABMs were developed during the research, of which the specific model details are discussed over the course of this dissertation, as well as in the annexes.

Furthermore, in Annex D, we detail how the information and insights from the semi-structured interviews were used to develop the agent-based models.In Chapter 6, we discuss how the results of the semi-strucured interviews and the agent-based models interplay with each other, thereby providing an answer to general research question 2. As such, we come to the true advantage of using a mixed-method approach, in which a qualitative research method and a quantitative research method are combined and their results integrated, in order to generate key insights to address organisational challenges for new applications in the context of the biobased economy.

1.7 Valorisation of maize in Flanders

To answer the general research questions presented above, we focus on local value chains of maize (*Zea mays subsp. mays*) in Flanders.

Flanders, the northern region of Belgium, is an interesting area with great potential for the development of a bioeconomy and biobased economy. Firstly, a clear political ambition has been expressed to further develop a bioeconomy. Indeed, in 2013 the Flemish government published a vision and strategy in which they state that the region “will be one of the most competitive bioeconomy regions in Europe” by 2030 (Departement Leefmilieu Natuur en Energie 2013, p.17). Secondly, the region is located in the centre of Northwestern Europe, with a good infrastructure and access to the ports of Antwerp, Ghent, and Zeebrugge[2], and has one of the highest concentrations of petrochemical companies in Europe (Vandermeulen et al. 2010). Hence, the knowledge and infrastructure needed for the further development of a biobased economy is already present. On the other hand, the region is also facing some challenges in further developing its biobased economy. For example, only a limited quantity of biomass is locally produced and competition for biomass is significant. Additionally, while the agricultural sector is considered very efficient, as it utilized limited agricultural land and

[2] The smaller port of Ostend, representing only about 0,5% of the goods turnover, and focusing mainly on the offshore wind business and the building industry, is considered less relevant for the Flemish biobased economy (Boelaert 2017).

workforce to create high added value products, extra local biomass production would be difficult because of the limited land availability (Vandermeulen et al. 2010). Indeed, Flanders is very densely populated leading to high pressure on open space (Kerselaers et al. 2013). This, in turn, leads to congested roads, posing a major challenge for efficient biomass transport.

Furthermore, the biobased economy is challenged by an ongoing public debate about food-versus-fuel production as well as the influence of the biobased economy on biodiversity or the use of harvest residues on soil organic carbon. Finally, the public funding climate is perceived as unstable by the processors, preventing them from making further investments (Vandermeulen et al. 2010).

Within the region of Flanders, we chose to focus on one crop, namely maize (*Zea mays)*, also referred to as corn. In this dissertation, we use the term “maize” when we speak about the crop in general, or when the crop is grown to be harvested in its entirety. We use the term “corn” when the crop is grown to harvest the grains, and the stover remains on the field or is harvested at a later stage. Occupying more than 25% of the agricultural land (Peeters 2010), maize is a very important crop in Flanders.

Both silage maize and corn have gained popularity since the 1970s. For example, figure 1.1 shows the evolution of silage maize in Flanders, which demonstrates its increase in popularity. According to (Haesaert 2003), this is due to the progressive specialization in livestock farming, especially dairy farming, and the optimization of silage maize cultivation and harvest.

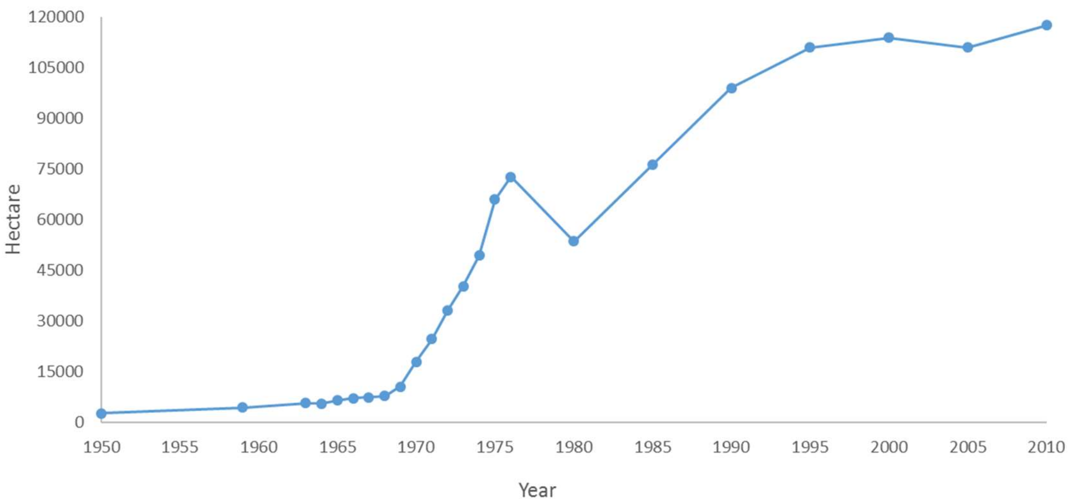


Figure 1.1 Evolution of the silage maize surface area in Flanders. Source: Boterdaele 1997; Vaes et al. 2014

Corn has also gained popularity in Flanders. Up until the 1970s, the crop was only cultivated on a limited scale and was mainly used as feed for poultry. As planting, harvesting, drying and grinding of the maize was all done manually, maize was a very labour intensive crop. From the

1970s, pig farming in Flanders became more important. A source for food was needed for these pigs and corn was a good candidate. In 1992, the Mc Sharry plan was introduced, which replaced price support with direct subsidies based on hectares, but payment was still linked to historically referenced quantities in tons produced (Haesaert 2003). This plan, in combination with the introduction of early-maturing and more productive corn varieties - which limited the cost of drying and increasing harvest security- further increased the cultivation of corn in Flanders (Haesaert 2003).

In the meantime, different corn and maize planting and harvest machines were being developed in the United States, which could almost be directly applied in the Flemish context. However, as the cost of these machines was substantial, single farmers could not make the investments themselves. Instead, only some of the farmers made the investments and then further valorised the machines by undertaking additional contract work on other farmers' fields. As such, over time more specialized contract workers and custom harvesters (CHs) came to the forefront in the maize cultivation process. Today, maize can be considered as the reference crop whereby sowing, herbicide treatment and harvesting are mostly done by contract workers or custom harvesters. This unique position of contract workers and custom harvesters[3] within the maize value chains make it an interesting case study from an organisational perspective.

As can be seen in Figure 1.2 maize has many applications within the biobased economy in general. Two types of maize are grown in Flanders: silage maize of which the entire plant is harvested and processed and corn of which only the grain is harvested and processed. Most of the maize cultivated in Flanders is silage maize (about 175.000 hectares) (FOD Economie-Algemene Directie Statistiek 2015). This type of maize is mainly used for the production of feed for dairy cattle (98%). About 2% of the silage maize is used as input for co-digestion for the production of biogas (Departement Economie Wetenschap & Innovatie 2012). In Flanders, about 65,000 hectares are planted with corn for harvesting grain (FOD Economie-Algemene Directie Statistiek 2015). In a report from 2012, it was stated that about 40% of this grain is used for the production of concentrates to be fed to pigs or cattle, or to poultry and 58% is used for the production of starches. A proportion of these starches is used in food processing. The remaining (7%) is used in the chemical industry for the production of textile, paper, pharmaceuticals and adhesives. About 2% of the grain is used to produce bio-ethanol (Departement Economie Wetenschap & Innovatie 2012). After the grain is harvested, the remaining parts of the plant, the stover, are usually left in the fields. Upon preparation of the field for the next crop, the stover is then ploughed into the field, serving as a source of soil

[3] In the remaining of this dissertation, we will use the term "custom harvesters" to indicate persons, owning specialized equipment for different cultivation processes, and using this equipment to execute these cultivation processes for themselves or for third parties.

organic carbon. However, today, technology exists to convert this stover into bio-ethanol (Aden et al. 2002), or into cellulosic sugars (Duffy & Marchand 2013), or used for other valuable applications, such as feedstock for anaerobic digestion, or as feedtock for particle boards. The many applications of maize within the bioeconomy and biobased economy make it an interesting case study for this dissertation.

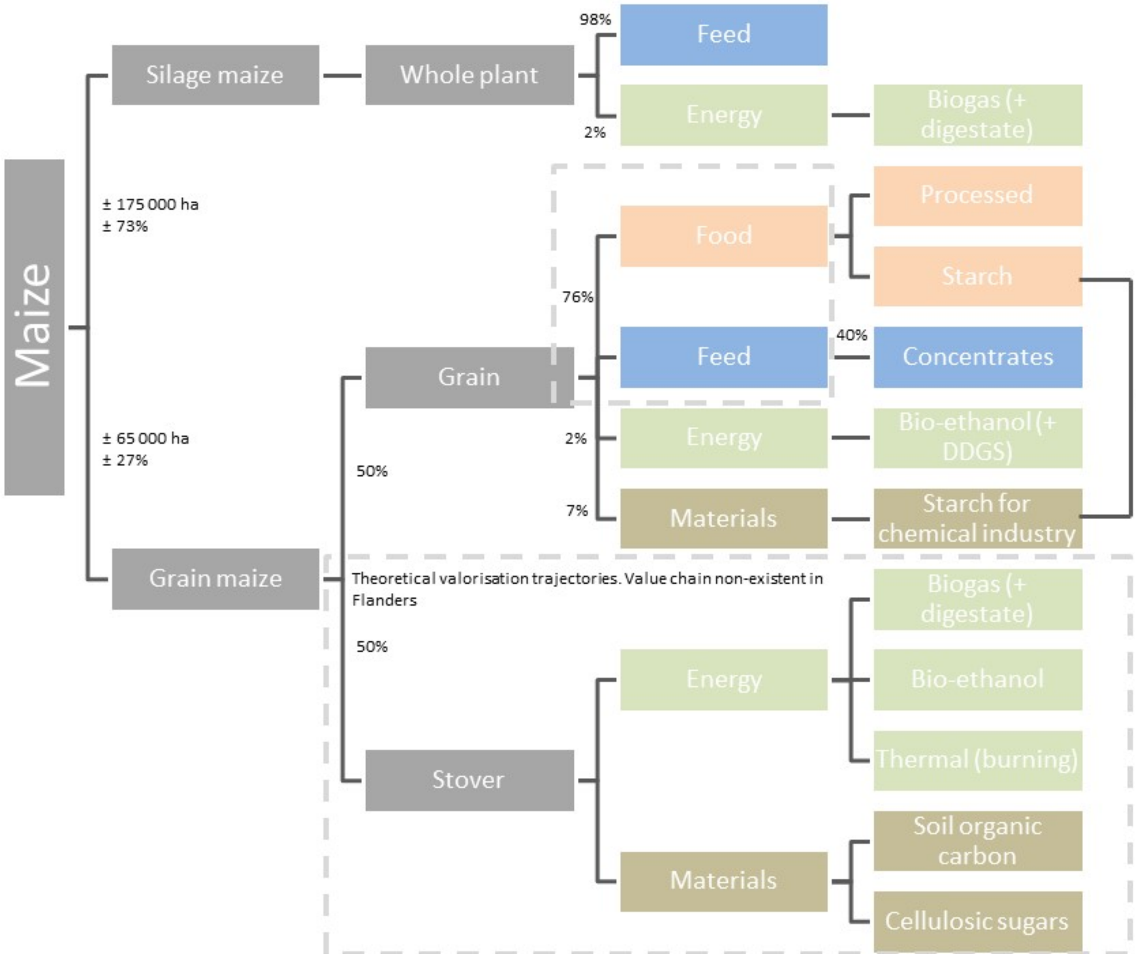


Figure 1.2 Valorisation trajectories of maize, divided into the four potential uses of biomass: food, feed, energy and materials. Scheme based on Lebuf 2011; Departement Economie Wetenschap & Innovatie 2012; Duffy & Marchand 2013.

Furthermore, as maize is a very important crop in Flanders, a lot of research has been conducted to improve its cultivation, harvesting and processing. As a result, the different stakeholders have a thorough knowledge of the technical aspects relating to the crop. In our research, we could therefore make use of the widely available technical, economic and techno-economic information available, making it easier to solely focus on the organisational aspects of the maize value chains in this dissertation.

Finally, maize is traded both internationally and locally and an interesting interplay takes place between international and local markets. Indeed, corn grain prices are determined on the global market. As the Flemish corn grain production is negligible on a global scale, decisions by the different stakeholders in Flanders have no influence on these global corn prices

(Vandermeulen et al. 2010). Hence, farmers can always decide to sell their corn grain to replace internationally imported grain and international prices. On the other hand, a proportion of the maize, namely silage maize is traded locally, and in this case decisions by the different stakeholders do have an influence on the local maize value chains and local prices. Hence, the farmers' decisions to sell the maize on the global market or to trade it locally can have potentially significant effects for processors of local biomass. This makes maize an interesting crop to investigate from an organisational perspective.

1.8 Corn stover value chain development in Ontario, Canada

1.8.1 Short historical background

Since the 1980s, the local chemical industry in Sarnia, a town situated on the shores of Lake Huron in the South region of Ontario, has been in a no growth phase and jobs are in decline. With the aim of giving the local industry a new boost, Bio-industrial Innovation Canada (BIC) conducted a study on alternative business opportunities for this town and its surroundings. Confined by the conditions needed for these opportunities to be sustainable and to make use of the existing infrastructure and local human capital, the BIC researchers decided to focus their research efforts and activities towards the facilitation of the development of a biomass value chain producing sugars as a central building block. Indeed, sugars were found to be the most commonly produced starting block in the chemical industry, and they could be made from renewable biomass. However, it remained unclear which biomass resource would be suitable for this value chain, as the researchers refrained from the assumption that biomass is abundantly available. Also, the researchers wondered which industries or companies would be interested in using the sugars produced. Raising those questions could be seen as the genesis of the development of a cellulosic sugar value chain in Ontario.

With the first question in mind, the BIC researchers conducted several studies in collaboration with the Ontario Federation of Agriculture (OFA). In 2011 and 2012, the published several reports on the biomass sources available in the area that could support an industry to produce 24/7, year-round. In order to avoid the food-versus-fuel debate, biomass sources under consideration were limited to non-food biomass, including purpose-grown crops such as miscanthus and switchgrass (Ontario Federation of Agriculture 2011; Kludze et al. 2011; Oo et al. 2012), as well as crop residues such as hay, wheat straw and corn stover (Oo & Lalonde 2012). After some research, miscanthus and other energy crops were found to be too expensive for use as biomass feedstock. Therefore, it was decided to narrow down the focus to wheat straw and corn stover.

Corn stover seemed interesting, but at the same time, little was known about the harvest and processing of this biomass source. Indeed, the first corn stover value chains were only being developed in the US for the production of bio-ethanol, while the goal here was to produce cellulosic sugars[4]. These cellulosic sugars can be processed, for example, into succinic acids, which can then be used for products now mainly produced from fossil-based resources, such as paints and coatings, plastics, plasticizers etc. In order to gain some insights into the feasibility of using corn stover for the production of cellulosic sugars and to explore the opportunities for the region, in the fall of 2012, a meeting was organized between farmers, technology providers, possible end-users, researchers and policy makers. Later on, in the winter of 2012, focus groups were also organized in which corn producers could express their initial thoughts about the development of a corn stover value chain, which resulted in a better understanding of the producers' interests and concerns.

In 2013, an advisory committee was established, consisting of 10 members and 2 observers, with representatives from BIC, local producers and farm organisations, local processors, including representatives from BioAmber and IGPC (Integrated Grain Processors Co-operative), researchers and policy makers. This committee would meet every 6 to 8 weeks with the goal of reviewing the progress of the work conducted by BIC and to provide input to the different techno-economic feasibility and logistics studies, including (Duffy & Marchand 2013; Marchand 2015). In the meantime, different agronomic and aggregation studies, as well as preliminary econic assessments, were conducted and harvesting demos were organized by the OFA. These studies demonstrated the potential for developing a viable and reliable corn stover value chain for the production of cellulosic sugars in Ontario. Furthermore, after a study conducted by Duffy and Marchand (2013) had shown that the preferred governance structure to manage the corn stover supply for a processor and provide a reasonable return to the producers would be the establishment of a bio-processing cooperation (Duffy & Marchand 2013), the Cellulosic Sugar Producers Cooperative (CSPC) was established on September 19 2014. At the end of 2016, the start of 2017, and end of 2017, several harvest demonstrations and town hall meetings were organized in order to inform the corn producers in the region about the establishment of the cooperative and to convince them to become members.

As the next step, the researchers at BIC studied different technologies that had the potential to economically convert corn stover into cellulosic sugars. In February 2016, the five board members of the CSPC selected Comet Biorefining as the preferred technology provider, after an in-depth analysis, evaluation and validation of 19 technology providers on their potential for

[4] With cellulosic sugars, we mean sugars (mainly glucose and dextrose) made from lignocellulosic biomass or woody crops and agricultural residues (i.e. second generation biomass resources), including corn stover.

commercial scale-up applications (CSPC 2017). Secondly, a specific business plan for the CSPC coop was developed, including all operational costs, as well as estimated financial returns (CSPC 2017). In April 2016, this company signed an off-take agreement[5] with BioAmber[6], which ensures the sale of the sugars not only to the plant in Sarnia, but also to future BioAmber plants. Comet Biorefining now plans to start the construction of the first commercial cellulosic sugar production plant in Sarnia, however, we could not find any update on when the construction works would start. The plant will be located within Sarnia's chemical industry next to the BioAmber plan, which has been in operation since October 2015. In order to ensure sufficient corn stover availablility for the plant, a first partial corn stover harvest is planned in 2017. In 2018, the first full-scale corn stover harvest is planned. Finally, the cellulosic sugar production plant should become fully operational late 2018 or 2019.

1.8.2 General overview of the corn stover value chain

Figure 1.3 shows an overview of different steps that will be taken to produce cellulosic sugars from corn stover in Sarnia. The value chain starts as a conventional corn value chain; the farmers cultivate the corn and harvest the corn with a regular combine. As the value chain should interfere as little as possible with the farmers' practice of growing in order to be able to convince farmers to participate, no special requirements are imposed concerning the corn variety grown or the harvest date. Indeed, selling the corn grain will remain their main source of income, while selling the corn stover is only seen as a way to gain additional income from the same plot of land. The rest of the activities in the value chain are organised and conducted by the CSPC. The campaign is expected to last about 90 days. Harvesting of the stover will be done in three steps:

1. An adjusted flail chopper cuts the stover into pieces. Thanks to the auger, the chopped stover is released onto the field in windrows instead of being dispersed over the field
2. A baler will pick up the stover and press it into 3 x 4 x 8 feet (0.9 x 1.2 x 2.4 meter) square bales. The weight per bale is one of the most important drivers of the costs in the corn stover value chain. Therefore, the cooperative will use a high compression baler, allowing to put 15% more weight to be put into a single bale. An additional advantage of using this high compression baler is that the corn stover is packed so densely that almost all the air is pressed out of the bale, which is beneficial for its

[5] The agreement guarantees the sale of about 80% of the produced sugars.

[6] BioAmber produces succinic acid from glucose and dextrose sugars derived from plant based materials. At the moment, they use sugars produced from corn grain, but in the future they hope to use cellulosic sugars. The succinic acid is sold worldwide to other companies that make products such as paints and coatings, plastics, adhesives, lubricants, plastizers, polyurethanes, artificial leather, etc.

conservation during storage. Furthermore, the bales do not easily fall apart when the strings come off.

3. The bales are collected by a bale stacker and brought to the edge of the field, where they stay until they are picked up by a larger truck for storage or processing.

Having the harvesting process completely conducted by the cooperative has two advantages: (1) farmers do not have to invest in new equipment (2) the custom harvesters will be specialized in harvesting corn stover, which will enable faster, more precise and more consistent harvesting.

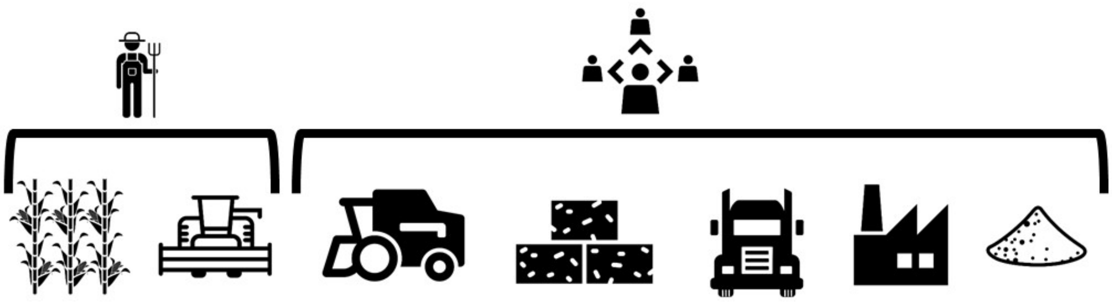


Figure 1.3 Schematic overview of the corn stover value chain. Corn cultivation and grain harvest is conducted by the farmers. Stover baling, harvest, transport and processing to cellulosic sugars is conducted by the cooperative.

After the stover is harvested it needs to be transported and stored. In order to ensure constant stover supply to the cellulosic sugar production plant, the cooperative aims to have a corn stover inventory of about 1.5 years. As the storage at the plant will only be limited, about 30% of the stover will be stored at a storage yard. The corn stover bales stored there, will be tarped to reduce the risk of quality loss during storage. Handling and transportation of corn stover bales has a significant impact on the total biomass cost. Therefore, it will be crucial for the cooperative to organise this as efficiently as possible.

The corn stover harvested and delivered by the cooperative will be processed by Comet Biorefining. In total, the plant will produce 50,000 tons of sugar per year, produced from about 75,000 tons of corn stover harvested from about 22.26 ha (55,000 acres) acres. At a very early stage, the original plan was to build a plant that could process up to 250,000 tons of corn stover annually. However, this plan was abolished because of the large investment and feedstock risks. Some respondents indicated that in time, the plant could possibly expand, once the value chain, the logistics and the technology had proven to be successful.

1.8.3 Governance structure: a bioprocessing cooperative

"So I think there is some value that we capture in there by working together and not, not against each other." (Farmer and board member of the CSPC)

The Cellulosic Sugar Producers Cooperative was established on September 19 2014. As explained before, the cooperative will be responsible for the organisation of the corn stover harvest. Furthermore, the cooperative serves as a vehicle for the farmers to be directly involved in the corn stover value chain, not only as producers of corn stover, but also as producers of the cellulosic sugars. Farmers who want to become member of the cooperative will have to buy shares, and at the same time commit a number of acres of corn from which the stover can be harvested and sold to the CSPC. At the moment, the price of one share is set at 200 Canadian Dollar (CAD) per acre, and a membership fee of 500 CAD. As the plant will process about 75,000 tons of corn stover or wheat straw per annum, this involves about 50,000 acres of corn stover. As such, the total investment of the CSPC will be about 10 million CAD, which is about 25% to 30% of the total investment needed for the plant. This investment allows the CSPC to have a couple of members on the Comet plant board of directors and to have 25% to 30% voting shares when management decisions need to be taken. For some issues, the CSPC has a veto right.

For each ton of stover harvested, the CSPC will pay the farmer 25 CAD per metric ton (with a moisture content of 15.5%). It was indicated by the respondents that this price should be sufficient for the farmers to make up for the loss in nutrients and SOC and still have some margin. In the case of adverse harvesting conditions for corn stover, the farmer can decide to supply wheat straw instead, which can also be processed by the plant. The price for wheat straw is set at 40 CAD per metric ton. Besides these flat rate prices, the CSPC members will also be given a dividend of the plant's profit, which is estimated to be 50 CAD per acre (Greig 2017).

In total, the CSPC is hoping to have between 100 and 200 members. Almost every farmer can become a member, as long as the farm is located within a 125 km radius of the plant and provided he wants to buy shares for at least 100 acres (about 40,5 hectares (ha). Smaller farmers are favoured less, because too many small farmers would significantly complicate the harvesting and logistics and increase the costs. Farmers can maximally commit 1000 acres (about 405 ha). In order to avoid a significant decrease in the soil organic carbon (SOC), several protection measures are put in place. Firstly, farmers are discouraged from committing more than 50% of their total corn area to the cooperative, in order to keep some flexibility in the fields from which the stover will be harvested. As such, the stover is not always harvested from the same fields. Secondly, farmers are encouraged to have corn-soybean-wheat rotation, as increasing rotation complexity would limit the effect of corn stover removal on the SOC (personal communication 2017). Moreover, only farmers with sufficiently high yields can participate (1.5 ton/acre (3.7 ton/ha) and 1.2 ton/ acre (2.97 ton/ha) for corn stover and wheat straw respectively) (Greig 2017). Finally, only 30% of the corn stover will be harvested from fields yielding more than 160 bushels an acre (10.76 tons per ha), as this would guarantee a sustainable residue harvest without affecting the SOC. However, some respondents questioned whether 30% was low enough. Farmers who no longer want to be members of the CSPC need to sell their shares to another farmer. At the moment of writing, the coop has about 40% of the necessary acres committed (Greig 2017).

The CSPC will be managed by a general manager and the cooperative board, which consists of 5 cooperative members: a president, a vice-president, a secretary and two advisors. The board is responsible for the daily decisions of the cooperative. Each year, the board will need to be elected, by all the cooperative members. Each member has one vote, regardless of the number of shares he has in the cooperative.

1.9 Specific research questions

As stated in section 1.5, the general objective of this dissertation is to **generate insights to address the organisational challenges of local biomass value chains in the context of the biobased economy.** In order to achieve this objective, we formulated three general research questions. In this research, we focus on local maize value chains, subdivided into four specific case studies. Given the focus on local biomass value chains, we disregard the more bulky maize value chains. In this respect, the use of corn grain for ethanol or feed was not studied in depth as the grain is traded on the world market and the local market has barely any influence. As can be seen in Figure 1.4, the case studies differ in the extent to which they consider competition for the local biomass or the focus on governance without competition, and the extent to which the case study deals with an existing local biomass value chain or the development of a new local biomass. The dotted line used in Figure 1.4 to divide the case studies in the quadrant signifies that the border between the groups is not absolute, and overlaps exist. Each case study allows us to answer one specific research question, helping us to answer the general research questions.

First, we focused on a case study involving an existing value chain, namely the silage maize market in Flanders, in which there is competition for the local biomass, in this case between the farmers and the biogas plant managers. For this case study we asked ourselves the following question:

Specific research question 1: Which factors contribute to the difficulties encountered by anaerobic digestion plant managers in obtaining a stable and affordable supply of silage maize biomass in Flanders?

Secondly, we investigated the development of a new value chain with great potential for the bioebased economy, namely the corn stover value chain. For this value chain, we focussed on investigating the potential of a corn stover value chain in Flanders, which is virtually non-existent at the moment, by examining the effect of competition and governance:

Specific research question 2: What is the potential for a corn stover value chain for large- and/or small-scale processing in Flanders? Can competition between large-scale centralized processing and small-scale decentralized processing enhance the development of such a value chain?

Specific research question 3: How does the organisation of the maize stover value chain influence its development and market characteristics over time?

Finally, we returned to an existing value chain, namely the corn stover value chain being developed in Ontario, Canada and compared it with the Flemish situation, in order to deduce lessons learnt for local biomass value chain development:

Specific research question 4: What lessons can we learn from corn stover value chains being developed in other regions?

As can be seen in Figure 1.4, answering these four specific research questions guides us in gaining insights to answer the three general research questions.

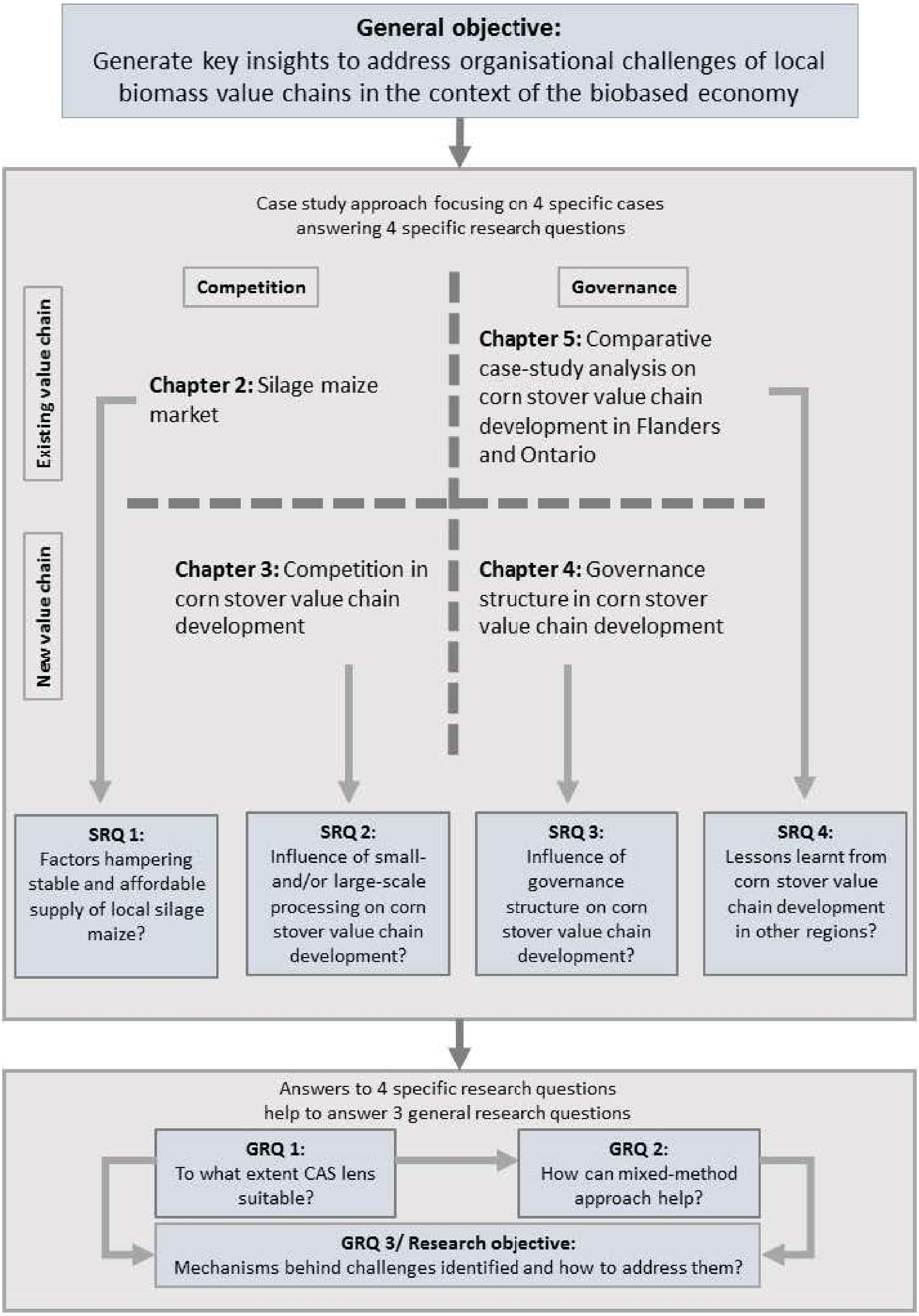


Figure 1.4 Overview of the research and dissertation structure.

1.10 Outline of the dissertation

Over the course of the following five chapters, answers will be provided to the research questions. The structure of this dissertation is presented in Figure 1.4. The following 4 chapters consist of a paper that is either published, under review, or planned for submission. In these papers, we zoom in on the specific research questions related to existing biomass value chains for maize, and the development of new maize value chains. While some repetition and redundancy can occur in these chapters, the papers are structured in such a way that the reader can easily skip overlapping sections.

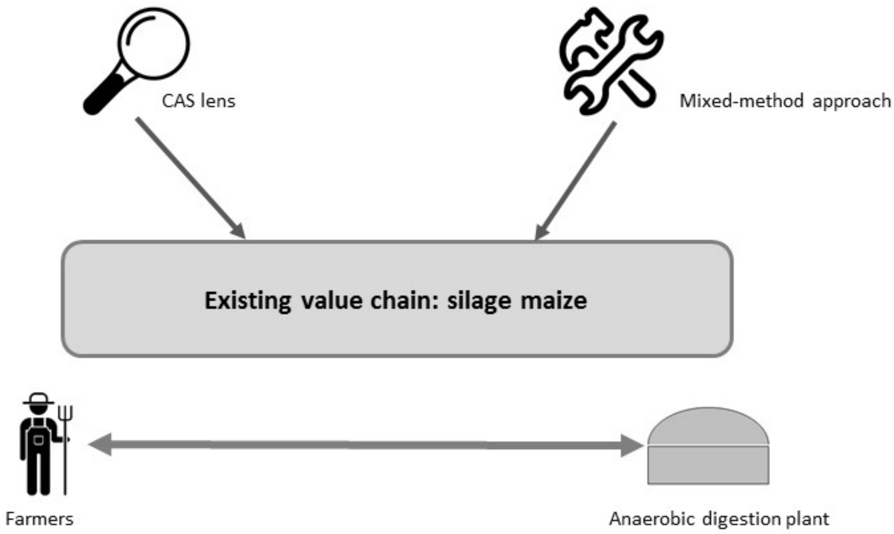
In chapter 2, we focus on the influence of market context on the supply of local biomass to anaerobic digestion plants. We investigate whether being a new entrant to the established silage maize market and using different institutional arrangements contributes to the difficulties encountered by anaerobic digestion plant managers in obtaining a stable supply of local biomass. Therefore, we use a sequential mixed-method approach of semi-structured interviews and agent-based modelling. First, we detail the insights gained from the qualitative research, focussing on the distinct trading rules and institutional arrangements of the silage maize market in Flanders, and more specifically on the difference between the institutional arrangements used amongst dairy farmers and those between dairy farmers and anaerobic digestion plant managers. Moreover, the market clearance and pricing of locally traded silage maize is discussed. Furthermore, we explain how these findings are translated into an ABM. Finally, we detail the results of a scenario analysis conducted using this ABM. The results of chapter 2 provide insights to answer specific research question 1.

In chapters 3 and 4, we focus on the corn stover value chain, as an example of the introduction and development of a new biomass value chain. In chapter 3, we detail an ABM developed to simulate the potential development of a corn stover value chain in Flanders when only one large-scale centralized processing plant is present, or when corn stover is used by many small-scale decentralized processing plants. Furthermore, we present the results of a scenario analysis to investigate whether competition between large-scale centralized processing and small-scale decentralized processing enhances the development of a corn stover value chain in a region like Flanders. The ABM makes use of the consumat approach, as a means to model the adoption of innovations over time. The model developed in chapter 3 was adjusted for use in chapter 4 in which we conduct a scenario analysis comparing different governance structures for the corn stover value chain. Chapters 3 and 4 contribute to the answers to specific research questions 2 and 3.

In chapter 5, we present the results of an in-depth case study analysis comparing the development of a corn stover value chain in Flanders and in Ontario, Canada. More particularly, using the integrated analytical framework developed by Lamprinopoulou *et al.* (2014), we aim to identify success factors and pitfalls for both case studies, in order to identify lessons learnt for the development of corn stover value chains in other regions in particular, and local biomass value chains in general. Chapter 5 provides insights to answer specific research question 4.

Finally, chapter 6 discusses the research results and presents the main conclusions. We provide answers to the general research questions. The novelty of our research approach is discussed, as well as advantages and difficulties encountered during the research. Furthermore, we present recommendations for practitioners and policy makers. Finally, we provide ideas for further research.

Chapter 2: Context matters – Using an agent-based model to investigate the influence of market context on the supply of local biomass for anaerobic digestion



Specific research question 1: Which factors contribute to the difficulties encountered by anaerobic digestion plant managers in obtaining a stable and affordable supply of silage maize in Flanders?

In this chapter, we depart from the observation that anaerobic digestion plant managers face difficulties in obtaining a stable and affordable supply of biomass. Therefore, we investigated which factors contribute to these difficulties and to what extent. After conducting semi-structured interviews, our hypothesis was that contextual factors may have a large contribution. Indeed, while silage maize is now used as input for anaerobic digestion, farmers use and trade silage maize already for many years. Four contextual factors could be identified:

(1) Different unit of transaction: farmers trade silage maize, negotiating a price for a particular piece of land, expressed in €/ha, while anaerobic digestion plant managers offer a price expressed in €/ton.
(2) Different safeguard measures: while farmers merely rely on durable relationships to protect themselves against opportunistic behaviour, anaerobic digestion plant managers prefer working with annual, legally enforceable contracts.
(3) The combination of (1) and (2) leads to silage maize price uncertainties. In general, silage maize prices tend to follow global prices of wheat and corn grain. However, the high transportation costs in combination with regional demand and supply differences result in largely inter-regional price differences. Furthermore, intra-regional price differences exist, as price agreements are sometimes complemented with other services besides the sale of maize (e.g. manure disposal).
(4) Later entry: The silage maize market has gradually developed over the years. Anaerobic digestion plant managers have entered this market later in time.

By simulating different scenarios with the help of an agent-based model and analysing its results, we were able to assess the relative contribution of two of these contextual factors towards the difficulties experienced by anaerobic digestion plant managers in obtaining a stable and affordable supply of local biomass. While the use of different safeguard measures seemed important from the qualitative research, the results of the scenario analysis showed their relative contribution remains limited. Instead, we found that a late entry into an informal market by anaerobic digestion plant managers increases the price volatility of the locally traded silage maize. As such the relative contribution of the late entry appeared to be more significant than initially assumed.

Abstract

Biogas plant managers often face difficulties in obtaining feedstock at stable and affordable prices. The context in which the biogas plant manager needs to purchase the feedstock could be important when the biomass is also used in valorisation trajectories besides anaerobic digestion. Using a combination of qualitative research and agent-based modelling, we investigated the effect of market context on the purchase of local biomass for anaerobic digestion. This paper details the institutional arrangements of our case study, the silage maize market in Flanders, and the results of a scenario analysis, simulating nine different market contexts. Silage maize is an interesting case study, as it is both used for feed by farmers and as an input in biogas plants. The results show that mainly the time of entry into the market explains the difficulties in obtaining a stable supply of silage maize to biogas plants. Furthermore, we found a silage maize price increase for farmers in competition with a biogas plant, especially in case of a silage maize deficit in the market. The different institutional arrangements used have no significant effect. Our findings may guide biogas plant managers in dealing with potential negative consequences when competing for local biomass sources, like local biomass price increases.

Keywords

Agent-based modelling, bioeconomy, silage maize, anaerobic digestion plants, informal trade, qualitative research

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2.1 Introduction

After the approval of the directive 2009/28/EC on the promotion of the use of energy from renewable sources by the European Parliament in 2009, important investments in anaerobic digestion plants were made, notably in Germany, Italy, Denmark, the Netherlands, Austria and Czech Republic (Eurobserv'er 2013). Also in Flanders, the northern region of Belgium, entrepreneurs established decentralized anaerobic digesters or biogas plants (Eurobserv'er 2013; De Geest et al. 2013).

However, today, biogas plant owners all over Europe face increased financial uncertainty, caused by high investment and operational costs (Gold & Seuring 2010) or low commodity prices for electricity (Eurobserv'er 2013). Additionally, in several European countries the public funding climate for the biogas sector has changed over the years. For example, the governments of both Germany and Italy lowered the feed-in-tarrifs for biogas plants (Eurobserv'er 2013). Additionally, in 2009 the Flemish government decided that biogas plants could profit from life-time subsidies for the produced energy. However this decision was repealed in 2012[7]. Moreover, many biogas plant managers encounter difficulties in achieving a stable and affordable supply of biomass (Poeschl et al. 2010; Edwards et al. 2015). In this paper, we focus on this last aspect, since it was identified as one of the main challenges of biogas plant managers in general (Gold & Seuring 2010; Poeschl et al. 2010; Edwards et al. 2015).

Previous research on biomass supply for biogas plants focussed on the perception of the plant managers on feedstock price uncertainty (Gold & Seuring 2010), or on more general aspects and barriers for the supply of biomass for bio-energy (Mccormick & Kåberger 2007; Gold & Seuring 2011). Van Sleen (2010) investigated the structures and types of contracts that may help in achieving increased investment security with regard to biomass costs. However, these studies generally do not consider the full context in which the biogas plant manager must acquire the feedstock. In particular, when the biomass type is also used in other valorisation trajectories, besides anaerobic digestion, this context could become of major importance.

In order to investigate the influence of context on the supply of local biomass to biogas plants, we focus on Flanders as a case study. Also in this region, locally produced silage maize is an important energy crop used by biogas plant managers. The crop accounts for about 13% of their total input (De Geest et al. 2014). On the other hand, silage maize is also widely used as feed source for dairy cows. Since many years, silage maize is traded amongst dairy farmers.

[7] Decree of 8th May 2009 Decreet van 8 mei 2009 concerning general provisions relating to the energy policy (*Decreet van 8 mei houdende algemene bepalingen betreffende het energiebeleid*). (De Geest et al. 2013)

This situation creates a specific context for the biogas plant manager; not only is he a new entrant into this market, he is also faced with the distinct institutional arrangements, or more specifically the unique trade rules for silage maize, which have developed over the years. These two issues can both affect the supply of local biomass to the biogas plants. In order to investigate importance of this contextual setting, we evaluated the following hypothesis: “Being a new entrant in this established market and using different institutional arrangements contribute to the difficulties encountered by biogas plant managers in obtaining a stable supply of local biomass”.

The evaluation of the hypothesis was done in three steps. First, we conducted semi-structured interviews with different stakeholders, including experts, dairy farmers and biogas plant managers. Based on the results of this qualitative research, we developed an agent-based model (ABM), simulating the trade behaviour of dairy farmers and biogas plant managers. In step three, we simulated three scenarios. Each scenario was tested for three different market conditions, resulting in simulations for a total of nine different market contexts. The results of this scenario analysis provide insight in the effect of interactions between dairy farmers and biogas plant managers on the emergent market, more specifically on the silage maize prices and the price volatility faced by biogas plant managers on the one hand and dairy farmers on the other hand.

The remainder of this paper is structured as follows. Section 2.2 describes the methodology used. In section 2.3 we detail the existing institutional arrangements in the silage maize market, focussing on the differences between trade rules amongst farmers and between biogas plants and supplying farmers. In this section, we also outline the agent-based model developed to test our hypothesis. Section 2.4 presents the results of the scenario analysis. We discuss our findings in section 2.5. The final section presents the main conclusions of our research.

2.2 **Materials and methods**

In order to investigate whether the context has an influence on the supply of local biomass to the biogas plant manager, we used a sequential mixed method approach. The methods used are detailed in the following paragraphs.

2.2.1 Qualitative research

To obtain insight into the institutional arrangements in the trade of silage maize in Flanders, we conducted semi-structured interviews. This kind of interviewing is a useful way to obtain a large amount of information in a limited amount of time (Bernard 2006). During the research process, the data were directly interpreted and further data collection was based on the previous collected knowledge. At first, semi-structured interviews were undertaken with experts. These were chosen based on the organisation they represented and their specific knowledge on the subject. They gave general insights in the trade of silage maize amongst dairy farmers, from which some general behavioural rules could be deducted. Additionally, they provided names of stakeholders involved in the trade of silage maize, including farmers, biogas plant managers and intermediary persons. Interviews with these respondents provided a more detailed and practical view on the silage maize market. The obtained information revealed that the market was characterized by distinct institutional arrangements. As a result, the insights gradually evolved from a more general comprehension of the situation towards a more detailed understanding of the governance structures and trade rules. Table 2.1 gives an overview of the interviews conducted. Once the authors had the impression no additional information was obtained by doing extra interviews, the qualitative research was ended.

Table 2.1 Overview of the respondents interviewed

Function	Number of respondents
Expert	3
▪ Advisor at economic consultancy organisation for dairy farmers	1
▪ Researcher at the umbrella organisation for research on fodder crops	1
▪ Advisor at farmers' organisation	1
Dairy farmer	5
Middleman	1
Dairy farmer with biogas plant	2
Biogas plant operator	3
Total number of respondents	14

2.2.2 Agent-based modelling

The results of the qualitative research were transformed into an agent-based model (ABM), as such models are fit to systematically gain qualitative insights into economic systems by sequentially testing different initial conditions (Tesfatsion & Judd 2006). ABM departs from the individual agents which are part of the system. North and Macal (North & Macal 2007, p.24) define agents as the "decision-making components in complex adaptive systems". A complex adaptive system was defined by Tesfatsion and Judd as a system that is "composed of interacting units" and that "exhibit emergent properties, that is, properties arising from the interactions of the units that are not properties of the individual units themselves" (Tesfatsion & Judd 2006). In our case, the agents could be the farmers or the biogas plant managers. In ABM, the behaviour of the individual agents, as well as the environment in which they operate, is modelled explicitly. The interactions and transactions between the agents result from these behavioural rules and are thus modelled implicitly, as is the market which emerges from these interactions and transactions. Furthermore, an ABM permits researchers to loosen some assumptions taken for granted in some other models, like economically rational behaviour or economic equilibria (Tesfatsion & Judd 2006). Finally, agent-based modelling allows the modeller to represent the reality in a natural way (Bonabeau 2002; Tesfatsion & Judd 2006; Matthews et al. 2007; Happe 2004; Negahban & Yilmaz 2014).

Multiple studies already used agent-based modelling to explore market mechanisms. For example, Kostadinov *et al.* (Kostadinov et al. 2013) developed an ABM in order to explore the characteristics of wood markets in Switzerland. Ostermeyer and Schönau (Ostermeyer & Schönau 2012) used the ABM Agripolis to explore the effects of biogas production on farms, farm structures and rural areas for the Altmark region in Germany. Heairet *et al.* (Heairet et al. 2012) investigated the development of the switch grass biofuel and bio-electricity market at the local level using an ABM. More detailed information on ABMs and Agent-based Computational Economics (ACE) can be found in (Tesfatsion & Judd 2006; Bonabeau 2002; North & Macal 2007; Borrill & Tesfatsion 2010). We developed our ABM using the Netlogo software (Wilensky 1999).

2.3 Insights in the case study gained from qualitative research

2.3.1 Background on the case study: silage maize trade between Flemish dairy farmers

As a result of the intensification of Flemish dairy farms, the use of silage maize as roughage has increased since the beginning of the 1970s (Haesaert 2003). Silage maize mainly provides energy and to a lesser extent proteins to dairy cows. The remaining nutrients and proteins are usually provided through grass and concentrated feeds. In order to minimize feed costs, the majority of farmers produces as much roughage as possible. However, because the availability of rural land in Flanders is declining due to competition with other functions (Kerselaers et al. 2013; Platteau et al. 2012), some dairy farmers do not have access to sufficient land in order to produce sufficient silage maize for their livestock. On the other hand, some farmers produce a silage maize surplus. Consequently, a silage maize market has gradually developed over the years, characterized by distinct trading rules and institutional arrangements. These are further detailed over the next paragraphs. Particularly, we focus on the differences between the institutional arrangements used amongst dairy farmers and those between dairy farmers and biogas plant managers. Finally, we discuss the price formation of silage maize and how this is influenced by different institutional arrangements.

2.3.2 Different unit of transaction: hectares versus ton

The unit of transaction is the first difference between transactions amongst dairy farmers and between dairy farmers and biogas plant managers. When farmers intend to trade silage maize, they negotiate on a price for a particular piece of land cultivated with silage maize, expressed in €/ha. Before an agreement is made, the farmers conduct a volume and quality check of the plot by walking through the field. This practice is not only time consuming, but also demands a certain experience. However, it is considered to be the most convenient approach, as most family farms have no equipment available to determine the harvested weight. Next, a price agreement is made orally, which usually includes that the seller is responsible for the cultivation of the maize, while the buyer is responsible for harvesting and transportation[8].

For biogas plant managers the situation is different. Dairy farmers with a biogas plant usually have the necessary agricultural knowledge to assess the quality of the field, while actual new comers in the market commonly do not have this knowledge. However, both types of biogas plan managers still purchase hundreds of hectares of silage maize yearly. Therefore, walking through every field they intend to buy is considered too time consuming. Moreover, all biogas plants are equipped with a weighing platform, which allows them to easily determine the volumes bought. Therefore, the biogas plant managers prefer €/ton as unit of transaction.

2.3.3 Different safeguard measures: durable relationships versus annual formal contracts

The closure of the agreement is the second major difference. As briefly mentioned in the previous paragraph, when both trading partners are farmers, the price agreement is usually made orally. Since these agreements are difficult to enforce legally, the farmers inquire additional safeguard measures against opportunistic behaviour. Generally, such measures manifest themselves in the form of durable relationships. By creating the expectation of continuity and longevity of the relationship, the wish for immediate return on investment is reduced. Instead, farmers focus on the profits that can be made in the long run with the durable relationship (Poppo & Zenger 2002), for example the ability to cheaply deposit manure, or to be the first in line to buy the trading partner's land when he would stop farming. Over the years, a feeling of trust and solidarity is growing between the trading partners, which further reduces the risk for opportunistic behaviour (Poppo & Zenger 2002).

This relational governance (Poppo & Zenger 2002; Williamson 1985; Palay 1985; Uzzi 1997; Cannon et al. 2000; Klein 2000) observed in transactions amongst farmers demands time and resources to be established (Palay 1985; Larson 1992; Cannon et al. 2000). For biogas plant managers, the investment costs in such relationships are high, as they need to work with many farmers. Hence, they prefer to work with annual, legally enforceable contracts. Each year a new price is negotiated and each year the farmer can decide whether or not to sell silage maize to the biogas plant. Some of the biogas plant managers interviewed indicated that they worked with yearly formal contracts, but at the same time tried to build up trust relationships with their

[8] Often other arrangements are part of the agreement as well, such as the deposition of manure by the buyer on the fields in question.

suppliers. This behaviour is supported by authors such as Cannon *et al.*(Cannon et al. 2000) and Poppo and Zenger (Poppo & Zenger 2002), who consider the use of formal contracts and relational governance not as substitutes but as complements. Others said they invested in trust relationships with few agricultural contractors to use them as middlemen between them and the silage maize suppliers.

2.3.4 Price formation of silage maize

The different institutional arrangements cause uncertainties about the silage maize prices. Several respondents stated that in general the silage maize prices tend to follow the global grain maize and wheat prices. However, local silage maize prices can largely deviate from these trends (Figure 2.1 and Table 2.2). Table 2.2 shows the correlation coefficients between the prices of different agricultural products: grain maize, wheat, roughage milk[9] (*Voeder Eenheid Melk or* VEM), and the protein component actually digested in the small intestine (*Darm Verteerbaar Eiwit* DVE). All correlations are significant ($p < 0.05$), except for the kDVE that has no significant correlations. Particularly, we observe strong correlations between the grain maize price, wheat and kVEM prices. The silage maize prices are only weakly correlated to the prices of the other products.

This different pattern can be explained as follows. Since silage maize has a low bulk density leading to high transportation costs, local demand and supply influence local silage maize prices. In regions with high density of dairy cows, farmers mentioned prices of about 2000 €/ha, while in regions with less dairy cows, farmers claimed to have paid about 1300 €/ha[10]. Besides these inter-regional differences, intra-regional price differences exist. As yield and quality differences can arise due to cultivation practices and quality of the plots, most respondents indicated that plots with higher yields or better maize quality tend to generate higher prices[11]. Furthermore, the aspiration to keep the durable relationship going drives buying farmers to pay higher prices or selling farmers to accept lower prices. Such large inter- and intra-regional price differences create price uncertainty amongst those interested in trading maize. Trying to tackle these uncertainties, farmers often discuss the prices with colleagues, including other farmers and agricultural contractors. Biogas plant managers without such a

[9] Dutch net energy system for dairy cows.

[10] Silage maize yields can differ largely between years due to the weather conditions. As a result, farmers with a silage maize surplus still tend to plant a surplus of silage maize in order to protect themselves from a possible bad harvest. Consequently, they will not easily switch to other more profitable crops.

[11] As farmers generally do not know themselves the exact volumes that were harvested and biogas plant managers are quite protective of their accountancy data, we were not able to gain access to quantitative data on exact prices and volumes to confirm this statement.

network are forced to rely on officially published prices of grain maize, wheat and kVEM which makes estimating a good silage maize price a challenging task.

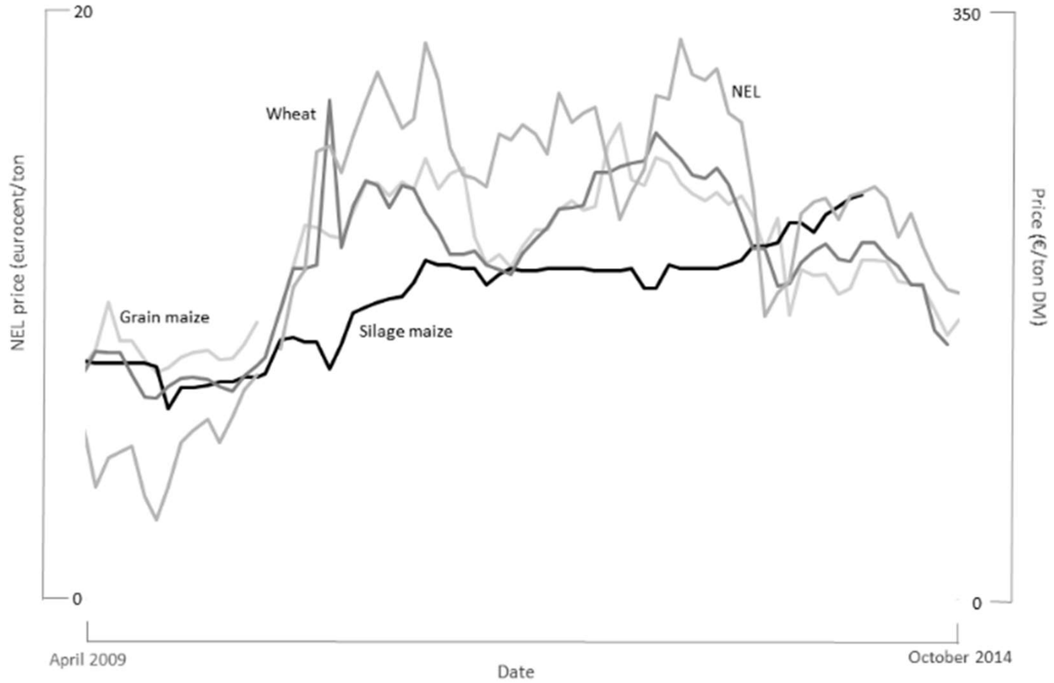


Figure 2.1 Price development of grain maize, wheat, silage maize (Wageningen UR 2014) **and roughage milk (kVEM)** (Wageningen UR Livestock Research 2014)

Table 2.2 Correlation coefficients between different agricultural products prices

	Grain Maize	kVEM	kDVE	Silage maize	Wheat
Grain maize	1.00				
kVEM	0.88	1.00			
kDVE	-0.20	-0.41	1.00		
Silage maize	0.59	0.69	0.06	1.00	
Wheat	0.91	0.90	-0.13	0.62	1.00

2.4 **Model for scenario simulation**

This section describes how we translated the findings of the qualitative research into an ABM. We do not have the intention to explain the full details of the model. For readers interested in the model details, a complete description following the ODD (overview, design concepts and details) protocol (Grimm et al. 2006; Grimm et al. 2010) is presented in Annex A.

It should be noted that the goal of the model is not to simulate reality and specific numbers, which allowed us make some simplifications. Contrarily and as mentioned in section 2.2.2, the goal of the ABM is to simulate the individual decisions of the different agents active on the silage maize market, in order to observe the characteristics of the market at the macro level.

Figure 2.2 shows a schematic overview of the model, which will be explained in more detail over the next paragraphs.

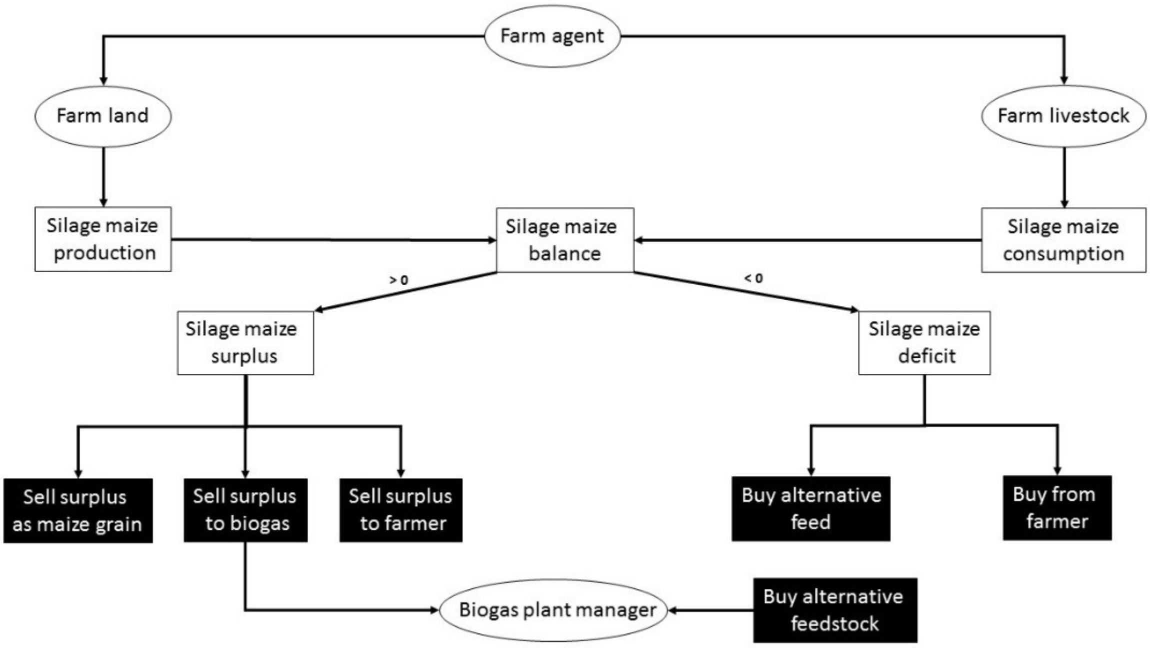


Figure 2.2 Schematic overview of the ABM. The farmers' and biogas plant managers' decision possibilities included in the model are indicated with a black background.

2.4.1 Agents

Two agent types are explicitly included in the model: dairy farmers and a biogas plant. They are located in a square of 400 square kilometer (km²), representing a high density dairy farming region in which farmers trade silage maize. The biogas plant is located in the centre of the simulated area, while the dairy farmers are randomly located in the remaining space. Dairy farmers have several hectares of farmland at their disposal for the cultivation of silage maize, and keep a certain number of cows. Data for these two parameters were retrieved from the Belgian Farm Accountancy Data Network (FADN) of 2012. With regard to the biogas plant, we used data for a hypothetical but realistic biogas plant in Flanders. We assumed that biogas plant managers do not keep dairy cows, nor any land for the cultivation of silage maize. Furthermore, we assumed that the introduction of the biogas plant has no effect on the business plan of the dairy farmers. This means that we kept for each farm both the number of cows and the surface available for producing silage maize constant during the simulation. Finally, concerning the cultivation and growth of silage maize, we assumed some differences in silage maize yield between different farmers, which can be related to the quality of the plots as well as different farming practices. Furthermore, yields vary between years in the model, simulating the influence of weather conditions. Table 2.3 presents the aggregated data used of the agents.

Table 2.3 Aggregated data of the agents simulated in the model

Parameter	Value/range [;]	Distribution
Number of farmers	104	
Number of biogas plants	1	
Average number of cows per farmer (standard deviation (σ))	102 (52)	
Average number of hectares for silage maize production per farmer (σ)	17 (11)	
Silage maize yield (ton DM/ha)	[15.4 ; 20.6]	Triangular
Yearly consumption of silage maize per dairy cows (ton DM/year)	[2.5 ; 3]	Triangular
Total silage maize production (ton DM/year) by all farmers	30,263	
Total silage maize demand from all farmers (ton DM/year)	28,644	
Total silage maize balance in absence of biogas plant (ton DM/year)	1585	
Number of farmers with a positive maize balance	58	
Number of farmers with a negative maize balance	46	
Total silage maize demand of biogas plant (ton DM/year)	3000	
Average total silage maize balance in presence of biogas plant (ton DM/year)[12]	-1030	

2.4.2 Markets

The model explicitly simulates two markets: the informal silage maize market amongst farmers and the formal contractual market between farmers and biogas plant managers. Additionally, three exogenous markets are considered to have an impact on the silage maize market: the maize grain market, the market of alternative feed for dairy farmers and the market of alternative feedstock for biogas plant managers. Although some agents are active on these exogenous markets, no interactions are explicitly modelled and the agents are not able to influence them. However, these markets do exhibit price fluctuations over time. For the maize grain market we took the evolution of the September maize grain prices for the period between 1999 and 2014 (Figure 2.3) (IndexMundi 2014). Prices of feed for dairy cows can be related to these prices of maize grain in two ways. Firstly, the daily requirements of energy are expressed as roughage milk (*Voeder Eenheid Melk or* VEM*)*, which is the Dutch net energy system for dairy cows. Secondly, the daily requirements and the supply of protein are expressed as *Darm Verteerbaar Eiwit* (DVE), which is the actual protein digested. Using the kVEM, kDVE and grain maize prices published by Wageningen UR (Wageningen UR Livestock Research 2014), we found a linear relationship between the kVEM price and the maize grain price. However, we found no correlation between the maize grain price and the kDVE price (Table2.2). As maize in Flanders is essentially grown for the glucan and xylan polymers it contains, and not so much for its protein content, this would most probably be the reason for the absence of correlation between the kDVE price and maize grain price. Therefore, it was decided to also randomize this price variation following a triangular distribution between 0.73 €/kDVE and 1.37 €/kDVE (Wageningen UR 2014). For anaerobic digestion, only the energy component of the biomass matters. Therefore, we calculate the price of alternative feedstock only based on the kVEM

[12] Average of 1000 simulations

prices[13]. More details on these correlations can be found in the description of the Overview Design and Details (ODD) of the model in Annex A.

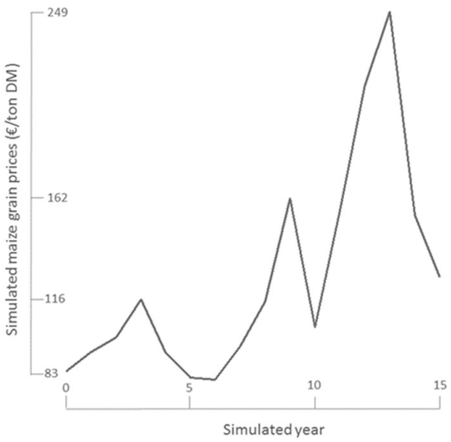


Figure 2.3 September maize grain prices between 1999 and 2014

2.4.3 Behavioural rules

At the start of each run, representing one year, the model calculates for each agent whether there is a silage maize surplus or deficit. Farmers with a surplus can make following decisions (Figure 2.2): they can sell the grains to the formal grain market for an exogenously determined price per ton, they can sell their surplus silage maize to another farmer, or they can sell their surplus to a biogas plant operator. Farmers with a silage maize deficit need to purchase extra feed in order to be able to feed their cows. They can either buy alternative feed on the formal feed market for a given price per ton, or buy some hectares of silage maize from another farmer. Biogas plant managers can also buy silage maize from farmers per ton, using annual contracts, or buy alternative feedstock for a fixed price per ton. When making their decisions, agents with a silage maize surplus follow a revenue maximizing behavioural strategy, while agents with a silage maize deficit follow a feed(stock) cost minimizing behavioural strategy. This purely rational behaviour is attenuated by the possibility to develop durable relationships as is common amongst farmers. This is discussed in the next paragraph.

2.4.4 Development of durable relationships

In order to include the development of durable relationships into our model, we based ourselves on the work conducted by Klos and Nooteboom (Klos & Nooteboom 2001). They

[13] The equations to calculate these prices can be found in the ODD. We related this to the prices of an alternative feedstock called Ecofrit, an alternative feedstock for biogas plants composed of several products, including organic biological waste, glycerine, fats, grains, and others. The biogas potential of this alternative feedstock is known to be between 160 and 185 Nm³/ton depending on the exact composition.

proposed the following equation to simulate the build-up of trust[14] ($trust_{ij}$) over multiple transactions between agent i and agent j:

$$trust_{ij} = b_{ij} + ((1 - b_{ij}) * \left(1 - \frac{1}{f z_{ij} + 1 - f}\right)) \qquad \text{(Equation 2.1)}$$

In this equation, b_{ij} is the basic level of trust between agent i and j, which can be interpreted as the initial friendship value between the two agents: when some farmers know each other better, they are more likely to interact with each other. Parameter b_{ij} is randomly and exogenously determined at the start of each simulation and varies between 0.3 and 0.9 amongst farmers. Furthermore, we assumed that the farmers do not really know the biogas plant manager, since he is a new entrant in the market. Additionally, based on the qualitative research we know that some farmers are more reluctant to sell their maize to a biogas plant for the production of energy instead of selling to another farmer as feed. Therefore, b_{ij} varies between 0 and 0.5 between farmers and the biogas plant manager. Parameter f is the trust factor, which determines how fast trust between two agents grows. Also this parameter is randomly and exogenously determined at the start of each simulation with the help of a triangular distribution between 0 and 1. In making this parameter random, we assume some agents build up trust faster than others. Finally, z_{ij} is the number of times the agent i has purchased silage maize from agent j. The more farmers interact, the higher the trust-level between those farmers. However, if a supplier defects, by selling his silage maize to another agent, the level of trust declines again, by reducing z_{ij} with 1.

2.4.5 Modelling trade

The trade of silage maize is simulated as a sealed bid auction repeated multiple times in order to simulate a negotiation process. In each auction round agents with a silage maize deficit make a price offer, expressed in €/ha to farmers with a silage maize surplus. The number of offers made by the agents, depends on the size of their own deficit compared to the overall silage maize deficit. Depending on the score they attach to each selling farmer (Equation 2.2), the agent determines to which farmers he will send a price offer. This score is calculated using a Cobb Douglas equation, modified from Klos and Nooteboom (Klos & Nooteboom 2001). The first term makes the balance between the costs for alternative feed and the costs for buying silage maize from another farmer. Because dairy farmers are responsible for harvesting and transporting the silage maize when they buy it from another farmer, these costs are taken into account.

[14] In this paper, trust is used in the sense of loyalty towards another agent to keep the trading relationship going.

$$score_{ji} = (\frac{P_{alt.feed} * Yield_{silage}}{bid_{ji} + harvest.costs + transportation.costs})^{\alpha_j} * trust_{ji}{}^{(1-\alpha_j)} \quad \text{(Equation 2.2)}$$

In Equation 2.2, the parameter α_i is the weight buyer j attaches to making profit, compared to staying loyal. This parameter is dimensionless and is assigned to each agent at the start of the simulations, using a triangular distribution varying between 0.5 and 1. To calculate the transportation costs, we used data from Mitterleitner *et al.* (2007) (Mitterleitner et al. 2007).

The bid made by agent j to agent i is calculated as:

$$bid_{ji} = Cr * maxWTP_j \quad \text{(Equation 2.3)}$$

$$Cr = 1 - v^5 \quad \text{(Equation 2.4)}$$

with $maxWTP_j$ the maximum willingness to pay (maxWTP) by agent j. We can assume that in reality, agents are not offering the full maximum WTP when they place a bid. Therefore, we adjusted the prices in analogy with Shastri *et al.* (2011) (Shastri et al. 2011), by multiplying the maxWTP with a factor Cr. In determining this Cr, bidders take into account two aspects: (1) the time that remains to be able to purchase the silage maize before the season is over (t) compared to the total time they make offers (T), and (2) the amount of silage maize they were already able to purchase (n) compared to their total demand (N). The parameter v is then:

$$v = max[\frac{n}{N}, \frac{t}{T}] \quad \text{(Equation 2.5)}$$

The bid will be closer to the maximum willingness to pay when the agent still has a large deficit or when he is running out of time. The Cr-value is adjusted each auction round. More details on how we calculated the maxWTP can be found in Annex A.

Farmers with a silage maize surplus receive these different bids, and need to choose whether they will sell to a farmer, the biogas plant operator or the grain market. they calculate a score for each offer (Equation 2.5). Different than in Equation 2.2, the first factor expresses the possible revenue made by selling silage maize to the agent that made the offer over the possible revenue made by selling the surplus to the grain market. By calculating this score, they can consider whether they sell their maize at the best price or stay loyal to friends or trading partners with whom they developed a durable relationship over the years.

$$Score_{ij} = (\frac{bid_{ji} * volume_{ji}}{P_{grain} * volume_{ji} * Yield_{grain}})^{\alpha_i} * (trust_{ij})^{(1-\alpha_i)} \quad \text{(Equation 2.6)}$$

Once the score is calculated, each farmer with a silage maize surplus chooses the farmer with the highest score to sell his silage maize. This auction round is repeated five times. If the farmers are not able to sell their surplus to other agents after the auction rounds, they sell it on the grain market. If a farmer with a silage maize deficit or the biogas plant manager is not able to purchase enough silage maize, they purchase alternative feed or alternative feedstock, respectively.

2.4.6 Weather variable

The environment, especially the weather, is crucial in determining the yield of silage maize. In years with beneficial environmental conditions, yields can be a lot higher than in years with bad environmental conditions. This inter-annual variation in silage maize yields was simulated through the introduction of a weather variable. In years with high yields, the increased supply of silage maize and decreased demand for silage maize, lead to a decrease in silage maize prices.

2.5 **Results of the scenario analysis**

In order to evaluate how different market characteristics influence the acquisition of local biomass by biogas plants, we conducted a scenario analysis including three scenarios:

- Scenario 1: dairy farmers and the biogas plant enter the silage maize market simultaneously and both agent types build up trust relationships with their suppliers. This scenario can be regarded as a reference scenario.
- Scenario 2: both agent types build up trust relationships with their suppliers. However, in this scenario, the biogas plant manager enters the market 10 years after the dairy farmers.
- Scenario 3: the biogas plant manager works with yearly contracts, and does not build up trust relationships with his suppliers. Additionally, he enters the market 10 years after the dairy farmers.

Comparing the results of scenario 1 with scenario 2 and 3, gives insight into the effect of a late entry in the market on the acquisition of silage maize. Comparing the results of scenario 2 and 3 gives insight into the effect of the use of different institutional arrangements. As the balance between local supply and demand could also influence the results, we did the scenario analysis for three market situations: (A) one with a structural silage maize deficit in presence of a biogas plant, (B) one in which local demand is more or less equal to local supply in presence of a biogas plant, and (C) one with a structural silage maize surplus in presence of a biogas plant. These market situations were simulated by copying the dairy farmers used in market situation A (see also Table 2.3) for market situation B and copying them again for market situation C. This means that in market situation A, there are 104 dairy farmers on the market, in market situation B 208, and in market situation C 312.

The results of the simulations, presented below, show the averages of the 1000 repetitions for each scenario (1, 2 or 3) in each market situation (A, B, or C). They do not have the intention to forecast market behaviour of specific farmers. Instead, the results should be interpreted in light of their capacity to explain the market dynamics and their effect on the acquisition of local biomass by biogas plant managers.

2.5.1 Effect of market characteristics on silage maize prices

Figure 2.4 shows the average prices paid by dairy farmers and the biogas plant manager for the three scenarios (1, 2, and 3) and the three market situations (A, B, and C) over the simulated time. Table 2.4 shows the average silage maize price paid by dairy farmers for the 15 simulated years together and the biogas plant managers from year 10 onwards[15]. From Figure 2.4, we immediately observe that the prices paid by biogas plant managers are higher than the prices paid by the farmers for the three market situations and the three scenarios. We found no significant difference ($p > 0.01$)[16] in the silage maize prices paid by the biogas plant manager when comparing the three market situations within the same scenario, nor when comparing the three scenarios within the same market situation for each simulated year. This indicates that nor the late entry into the market, nor the use of different institutional arrangements affects the average prices paid by the biogas plant manager. Also, the amount of silage maize available on the market does not lower the silage maize prices paid by the biogas plant. In all three market situations, the price paid by the biogas plant manager does not differ significantly from the price for the alternative feedstock ($p > 0.01$) in each year for scenario 1 and 2. For scenario 3, the price sometimes deviates from the feedstock price, namely in year 13 for market situation A, and in year 14 for market situation B and C. Furthermore, the prices largely follow the trend of the grain maize prices used in the model (Figure 2.3).

Looking at the average prices paid by the farmers, we found that in all three market situations (A, B, and C) for each simulated year, the prices in scenario 1 are significantly higher ($p < 0.01$) than in the two other scenarios. Furthermore, we found no significant difference ($p > 0.01$) between the prices paid in scenario 2 and 3. Hence, when there is competition with the biogas plant from the start, farmers pay a significantly higher price. On the other hand, whether the biogas plant manager builds up trust relationships or not, does not affect the average prices paid by the farmers. We found an exception to these findings for year 10 in market situation A, where we found no significant difference between the prices paid in scenario 1 and 2 and 3.

[15] We made this choice in order to be able to compare the prices paid by the biogas plant, as for scenario 2 and 3, he is only present on the market at year 10.

[16] For all statistical significance tests, we used a Mann-Whitney U-test

This is the year the biogas plant manager enters the market in scenario 2 and 3. After the entry year, the prices are again lower than the prices of scenario 1. Additionally, we found that the price increase for scenario 2 between year 9 and year 10 is significantly higher ($p < 0.01$) than the price increase between year 9 and 10 for scenario 1. The observed result suggests that farmers in this year are affected by the entrance of the biogas plant in the market. The sudden competition makes farmers react by increasing their prices to the level of scenario 1. Hence, when there is a silage maize deficit in the market, trust relationships between farmers seem not robust enough to cope with the competition induced by the biogas plant manager. However, we did not observe this effect for the other market situations.

Comparing market situation A with market situation B for each simulation year in each scenario, we found a significant lower price ($p < 0.01$) starting from year 9 (scenario 2 and 3) and 10 (scenario 1) when there is more silage maize in the market. We also found a significant price decrease ($p < 0.01$) between market situation B and C for scenario 3 starting from year 11. However, we found no significant price decrease between market situation B and C for scenario 1 and 2, except for in year 14.

From Figure 2.4, it can also be observed that the difference between scenario 1 and scenarios 2 and 3 from year 10 onwards, is larger in market situation B than in market situation A, and even larger in market situation C. This indicates that when there is more silage maize in the market , the farmers' silage maize prices are less affected by the competition with a biogas plant entering the market in a later stage. Hence, under these circumstances, the trust relationships between the trading partners that have developed are more solid and suppliers are willing to accept lower revenues in order to keep the relationship going.

Furthermore, in all three scenarios and market situations in each simulated year, the average silage maize price paid by the farmers stays significantly below the price of the alternative feed ($p < 0.01$). Hence, by trading silage maize, farmers can largely reduce their feed costs. Finally, the average prices paid by the farmers somewhat follow the prices of grain maize in the model (Figure 2.3), but to a lesser extent than the biogas plant manager's prices. Especially when there is sufficient silage maize in the market (market situation B) or a surplus (market situation C), the price peaks are less pronounced compared to the price peaks experienced by the biogas plant manager. This trend can also be observed by looking at the silage maize price volatility experienced by the two agent types, discussed in the next section.

Table 2.4 Overall average prices paid by dairy farmers over the 15 simulated years and the biogas plant manager from year 10 onwards for the three scenarios (1, 2, and 3) and the three market situations (A, B, and C). The standard deviations are added in round brackets.

	Scenario 1		Scenario 2		Scenario 3	
	Farmers	Biogas plant manager	Farmers	Biogas plant manager	Farmers	Biogas plant manager
Market situation A	70.34 (29.57)	124.66 (29.67)	64.27 (27.75)	124.55 (29.70)	64.79 (28.32)	124.90 (29.87)
Market situation B	68.17 (26.95)	124.47 (29.79)	62.12 (25.96)	124.55 (30.03)	62.20 (26.10)	124.85 (30.00)
Market situation C	67.77 (26.03)	124.62 (29.69)	61.50 (25.15)	124.41 (29.72)	61.14 (25.20)	124.66 (30.03)

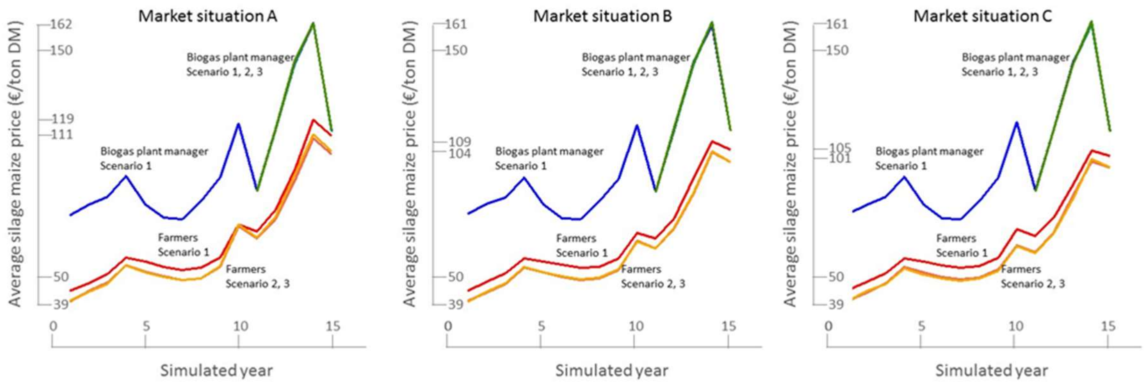


Figure 2.4 Average prices paid by dairy farmers and biogas plant manager for silage maize for the three scenarios (1,2 and 3) and the three market situations (A, B, and C)

2.5.2 Effect of market characteristics on the silage maize price volatility

Table 2.5 and Figure 2.5 show the average volatility of the silage maize prices paid by the biogas plant manager and the dairy farmers for the three scenarios (1, 2, and 3) and the three market situations (A, B, and C). We calculated this as the standard deviation of the silage maize prices paid by the agents over the period they are active in the market. The results show some interesting mechanisms.

Overall, in each scenario and market situation, the silage maize price volatility is significantly higher ($p < 0.01$) for the biogas plant manager than for the farmers. With regard to the silage maize price volatility for the biogas plant manager, there is no significant difference ($p > 0.05$) in volatility between the three market situations within the same scenario. However, comparing the different scenarios within the same market situation, we found a significant difference ($p < 0.01$) between scenario 1 and scenario 2 and scenario 1 and 3. Hence, a late entry of the biogas plant in the market, increases his price volatility. Additionally, we found no significant difference in volatility between scenario 2 and scenario 3 ($p > 0.01$), indicating that building up trust relationships does not lower the price volatility of silage maize.

The volatility of the prices for the farmers remains more or less the same when comparing the three scenarios within each market situation. Only for market situation A, we found a significant difference ($p < 0.01$) in the price volatility between scenario 1 and scenario 2 and scenario 1 and 3. Hence, when there is a shortage of silage maize in the market, a late entry of the biogas plants increases the silage maize price volatility for the farmers. Furthermore, comparing the different market situations within each scenario the silage maize price volatility decreases significantly ($p < 0.01$) when there is more silage maize in the market. This confirms our findings of section 2.5.1 that in case of a silage maize shortage in the market, the farmers are more affected by the competition with the biogas plant and trust relationships between farmers are not robust enough to counter the competition. However, in case of sufficient silage maize in the market or a surplus of silage maize in the market, farmers are less affected.

Table 2.5 Average volatility of the silage maize prices paid by the dairy farmers and the biogas plant managers for the different scenarios (1, 2, and 3) and different market situations

	Scenario 1		**Scenario 2**		**Scenario 3**	
	Farmers	Biogas plant manager	Farmers	Biogas plant manager	Farmers	Biogas plant manager
Market situation A	23.42	28.56	25.29	31.60	25.87	31.84
Market situation B	15.46	28.51	16.00	31.93	16.01	31.89
Market situation C	10.99	28.59	10.17	31.57	10.16	31.91

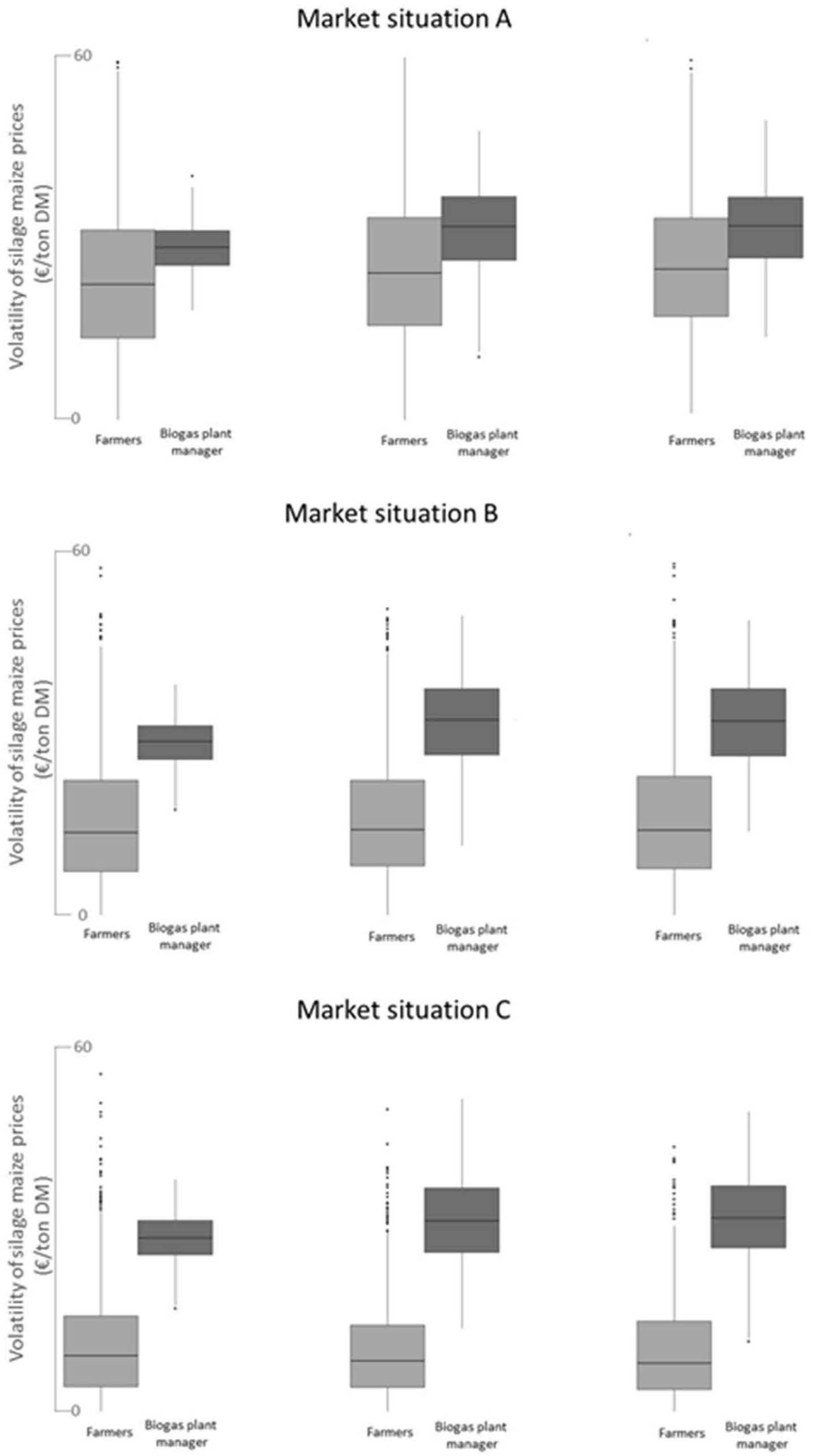


Figure 2.5 Volatility of the silage maize prices paid by the dairy farmers and the biogas plant manager for the different scenarios (1, 2, and 3) and different market situations (A, B, and C)

2.6 Discussion

The model results allow us to evaluate our hypothesis: “Being a new entrant in the established silage maize market and using different institutional arrangements contribute to the difficulties encountered by biogas plant managers in obtaining a stable supply of local biomass”. Our results confirm that a late entry contributes to these difficulties. In this situation, the average silage maize prices paid by the biogas plant manager are not affected. On the other hand, the volatility of these prices rises significantly in comparison with a simultaneous entrance with the farmers.

With regard to the farmers, a late entry of the biogas plant managers increases their silage maize prices. This effect is more prominent when there is a shortage of silage maize in the market. Additionally, only in case of a shortage of silage maize in the market, the late entrance of the biogas plant manager slightly increases the silage maize price volatility of the farmers. In case of a late entry, most suppliers have already build up a trust relationship with other farmers at the moment the biogas plant manager enters the market. When there is a deficit of silage maize, the competition for the biomass resource is stronger. As mentioned earlier, we found no significant difference between the silage maize prices paid by the biogas plant manager and the prices of the alternative feedstock. On the one hand, as the biogas plant manager needs a large volume of feedstock, he will not be willing to pay a higher price than the alternative, because this would largely increase his overall feedstock cost. On the other hand, he does not seem to be able to purchase silage maize at a significant lower price. Indeed, he is inclined to pay a price which is a lot higher than the price paid by the farmers. Hence, the biogas plant manager himself does not make a difference between silage maize or alternative feedstock. For the farmers with a silage maize surplus, it does make a difference, as they are able to sell their surplus at much higher prices to the biogas plant than to other farmers. Despite the trust relationships, the suppliers of the farmers switch to supplying the biogas plant at higher prices. When there is sufficient or a surplus of silage maize in the market, these effects are less significant. This indicates that trust relationships are more vulnerable in case of significant competition for the same biomass source.

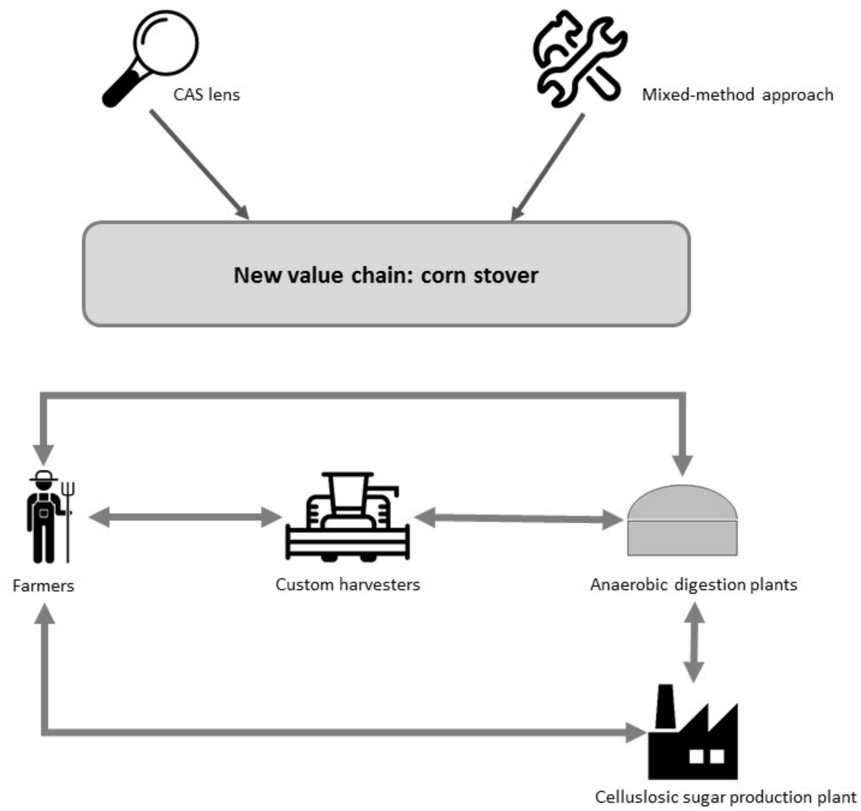
Gold and Suering (Gold & Seuring 2010) found that local rootedness and social capital can help in reducing the difficulties in local biomass supply. However, according to our results, whether the biogas plant manager builds up trust relationships with the farmers or not does not affect the prices paid by both actors, nor their volatility. As the costs related to the development of trust relationships could be significant due to the time and resources that need to be invested, we are inclined to say that gains resulting from investing in trust relationships do not outweigh the benefits.

Of course, interpretation of the model results should be done in light of the assumptions made. First of all, we assumed that farmers do not change their cultivation plan, or the number of dairy cows over time. In reality, we could wonder whether the introduction of a biogas plant would influence these parameters. Ostermeyer and Schönau (Ostermeyer & Schönau 2012) found that farms with biogas production would increase the share of grass and maize silage in the crop mix. However, it is difficult to estimate if these results would apply in Flanders, since their assumptions are difficult to compare with our case study. In their model, they have included much larger farmers that have their own biogas plant with their own silage maize production. Therefore, their model does not simulate trade of silage maize between actors. This is different to our case study, as the large majority of the biogas plants needs to purchase silage maize from local suppliers. Secondly, we assumed a triangular distribution for parameters when no empirical data were available. This was the case for the weight the agents assign to having maximum revenue or minimal feed(stock) costs as opposed to staying loyal to previous trading partners (α in Equation 2.2 and 2.4), the trust factor (f) and the base level trust (b) (Equation 2.1). Finally, the model did not include all the possible market mechanisms that could influence the price formation or the trust relationships. For example, a farmer might want to pay more for the silage maize if he could deposit the manure of his cows on the fields of the supplier, trust relationships could break if farmers get into a fight over other issues, or bad weather conditions could completely destroy the yields. Deciding to leave these details out of the model was a question of finding the right balance between increasing complexity to approximate reality and still being able to interpret the results. We chose to keep the model fairly simple, since our purpose was not to predict exact outcomes, but to acquire insights into the way certain market characteristics could influence market outcomes. The results may already contribute to the development of strategies for the difficulties of biogas plant managers to acquire local biomass. In extension, the research question and results are relevant for all new plants related to a bio-based industry that have to operate in similar market conditions.

2.7 Conclusion

This paper presents the results of a mixed-method research involving semi-structured interviews and agent-based modelling to investigate the effects of market context on the purchase of local biomass by biogas plants. The semi-structured interviews revealed that the silage maize market amongst dairy farmers is characterized by distinct trade rules and institutional arrangements, that differ largely from the institutional arrangements used between biogas plants and dairy farmers. Translating these findings into an agent-based model, we found that a late entry into an informal market by biogas plant managers increase the price volatility of the local silage maize. Additionally, when there is a deficit of silage maize in the market, farmers experience a price increase in presence of a biogas plant and a slight rise in price volatility when the biogas plant enters the market. When there is sufficient or a surplus of silage maize in the market, the effects of the presence of a biogas plant are less significant. Previous studies on the purchase of biomass by biogas plant managers often did not include the context in which these managers need to operate. With this study, we demonstrate the importance of the local context. Our findings may guide biogas plant managers in assessing and reducing the consequences of the establishment of a biogas plant using biomass that is also used in other local valorisation trajectories.

Chapter 3: Corn stover market development in regions with smaller scale agriculture. Can resource competition be beneficial?



Specific research question 2: What is the potential for a corn stover value chain for large- and/or small-scale processing in Flanders? Can competition between large-scale centralized processing and small-scale decentralized processing enhance the development of such a value chain?

In this chapter, we investigate the potential of a corn stover value chain in Flanders, both for large-scale centralized processing, such as the production of cellulosic sugars, or small-scale decentralized processing, such as the use of corn stover as feedstock for anaerobic digestion. Furthermore, we investigate if competition between these two could enhance corn stover value chain development. Analyzing the results of a scenario analysis using an agent-based model, we are able to understand the different mechanisms that contribute to or hamper corn stover value chain developed, and clarify their interrelationship. We find that under a spot market governance structure, a corn stover value chain is hardly developed when only anaerobic digestion plant managers are active on the market, and a large-scale centralized processor is needed to enhance its development. However, in competition, the multiple small-scale decentralized anaerobic digestion plants can readily take over a competitive position, thanks to the lower transportation costs. Furthermore, we find that farmers' participation rate is highly fluctuating, which implies that for large-scale processing the value chain is unlikely to be economically viable. Hence, under the modelled direct sale governance structure and the current conditions, we see no real potential for a corn stover value chain in Flanders. However, the results can guide the further research, exploring conditions under which such a value chain would be possible in Flanders, such as other governance structures, or a middle-scale processing facility.

Abstract

In light of a growing biobased economy, new and local biomass value chains will need to be developed. Thanks to its many possible applications, corn stover is perceived as an interesting biomass source for the biobased economy. While corn stover value chains are being developed in large-scale agricultural areas in the United States and Canada, in smaller scale agricultural regions they remain non-existent. With an agent-based model, we investigated the development of a corn stover value chain in such a smaller scale agricultural area, Flanders, in case of large-scale centralized processing, small-scale decentralized processing or competition between two processing types. Our results indicate that the presence of a large-scale centralized processor mostly relying on corn stover, enhances the development of a corn stover value chain. When only small-scale decentralized processing plants are active on the corn stover market, the development of the value chain remains limited. Furthermore, when stover supply is limited, the small-scale decentralized processing plants can readily take over a competitive position thanks to their decentralized location and the associated lower transport costs. The results presented in this paper can be used to guide the successful future development of a corn stover value chain in a smaller scale agricultural region like Flanders.

Keywords

Corn stover; agent-based modelling; development of innovative value chains; competition

3.1 Introduction

Yearly, millions of tons of corn stover are left on the corn fields, as a remainder of the corn plant after the grain is harvested. Over the past decades, research has shown that it is possible to harvest part of the corn stover without having significant adverse effects on the soil organic carbon (Wilhelm et al. 2004; Blanco-Canqui et al. 2007; Reijnders 2013; Gallagher & Baumes 2012; Kludze et al. 2013) and in an economically viable way (Sokhansanj & Turhollow 2002; Petrolia 2008; Aden & Foust 2009; Hess et al. 2009; Babcock et al. 2011; Gan & Smith 2011; Sokhansanj et al. 2010; Thompson & Tyner 2014; Perlack & Turhollow 2003). Furthermore, corn stover has many potential applications: it can be used for feed (Oji et al. 1977; Nennich et al. 2003; Lascano & Heinrichs 2011; Moreira-Filho et al. 2013), combustion, (Bennett et al. 2007; FEL 2009), digested for biogas (Schroyen et al. 2014; Song et al. 2014) and the production of cellulosic bio-ethanol (Gnansounou & Dauriat 2010; Sassner et al. 2008; Luo et al. 2009; Thompson & Tyner 2014) and cellulosic sugars (Marchand 2015). Thanks to these characteristics, corn stover is seen as an interesting source of biomass for the biobased economy.

However, in order to market corn stover, new value chains need to be developed. Value chains are a “set of interdependent economic activities”, such as harvesting, transporting and processing, which are undertaken by “a group of vertically linked economic agents”, such as farmers, custom harvesters and managers of processing plants (Bellù 2013, p.3). A corn stover value chain can only be successful if the different interdependent economic activities are well aligned with each other and if all economic agents are involved. Hence, participation of farmers as corn stover suppliers is required and a price should be obtained that is satisfactory to them. Moreover, processors should obtain sufficient amounts of stover given their processing capacity, by paying a price that is also satisfactory to them.

The potential of corn stover value chains also depends on the scale of both agriculture and processing (Ruan et al. 2008). For example, corn stover value chains are being developed in Iowa, United States (US) (Dupont n.d.; POET-DSM 2017), for the production of cellulosic bio-ethanol and in Ontario, Canada, for the production of cellulosic sugars (CSPC 2017). These regions are characterized by large-scale agriculture, with farmers cultivating on average 140 hectares (USDA 2015) and 99 hectares (Ontario Ministry of Agriculture Food and Rural Affairs 2017) of land in Iowa and Ontario respectively. This implies that a relatively limited number of farmers is required to collect a critical volume of corn stover in order to make large-scale processing possible, such as the production of cellulosic ethanol or cellulosic sugars. In other agricultural areas, with smaller scale agriculture, the development of a corn stover value chain for large-scale production might be complicated, as more farmers will need to be involved.

Therefore, the following questions arise. In areas with smaller scale agriculture in comparison to the US or Canada, is it possible to meet the conditions mentioned above in order to successfully develop a corn stover value chain for large-scale processing? Or should a corn stover value chain in these regions rather focus on small-scale decentralized processing? Or can competition between large-scale centralized processing and small-scale decentralized processing enhance the development of a corn stover value chain in such regions?

In order to address these questions, we developed and agent-based model (ABM). Agent-based modelling is a bottom-up modelling approach, particularly useful to systematically gain qualitative insights into economic systems by testing different scenarios (Tesfatsion & Judd 2006). Moreover, agent-based modelling allows to take into account the behaviour of the individual economic agents involved in the value chain. As such, it allows to better understand the conditions and mechanisms that influence the characteristics of the developing value chain, including corn stover supply levels and prices. We applied the ABM to the case study of Flanders. In this region, the average farmer cultivates about 25 hectares of land. Together, about 7500 farmers produce about 400,000 ton dry matter (DM) of corn stover yearly (FOD Economie-Algemene Directie Statistiek 2014). Hence, in order to make large-scale processing possible, a majority of the farmers should be involved in the supply chain. However, in Flanders, corn stover could potentially also be an interesting input for anaerobic digestion plants, as prices of the other inputs, like silage maize, are rising (Wageningen UR 2014). Using the agent-based model, we simulated three scenarios, providing insights in the development of a corn stover value chain in the presence of (1) one large-scale centralized processor, a cellulosic sugar production plant (CSPP), (2) multiple small-scale decentralized processors, being biogas plants and (3) a combination of small-scale and large-scale processors.

The remainder of this paper is structured as follows. In section 3.2, we explain the method used, namely agent-based modelling, and outline the ABM developed to answer our research question. Section 3.3 presents the model results, which are discussed in section 3.4. Section 3.5 presents the main conclusions of our research.

3.2 Methods

3.2.1 Agent-based modelling

In an ABM the behaviour of individual agents is modelled explicitly, as well as the environment in which they operate. In our case, agents are farmers, custom harvesters, and processing plant managers. They follow behavioural rules, which we derived from semi-structured interviews, expert knowledge, and literature. The different interactions and transactions resulting from these behavioural rules lead to the formation of a market with certain characteristics. Agent-based modelling allows to take into account the heterogeneous, bounded rational, sociological and strategic decision making aspects of economic agents. Therefore, some assumptions from other modelling approaches, such as economic rational behaviour or economic equilibria can be relaxed (Hammil & Gilbert 2016; Tesfatsion & Judd 2006). Furthermore, agent-based modelling allows the modeller to represent economic systems in a natural way (Tesfatsion & Judd 2006; Matthews et al. 2007; Happe et al. 2004; Negahban & Yilmaz 2014; Kostadinov et al. 2013).

Multiple studies have used ABMs to gain insight in market mechanisms in biomass value chains. For example, Heairet *et al.* (2012) investigated the development of switch grass biofuel and bioelectricity market at the local level using an ABM. Shastri *et al.* (2011) developed an ABM to explore the adaptation of Miscanthus production by farmers in Illinois and the impact on biorefinery capacity and contractual agreements. Gan *et al.* (2014) used agent-based modelling to estimate corn stover removal rates and the transboundary effect along the bioenergy value chain in Iowa. Finally, Mertens *et al.* (2016) developed an ABM to assess the impact of market context on the supply of local biomass for anaerobic digestion plants. More detailed information on ABMs can be found in (Tesfatsion & Judd 2006; Matthews et al. 2007; North & Macal 2007; Borrill & Tesfatsion 2010). We developed our model in R (R Core Team 2015).

3.2.2 General description of the agent-based model

This section briefly describes the main idea behind the ABM we developed. As we do not have the space, nor the intention to explain the full details of the model in this paper, readers, interested in specific model details, can have access to a complete model description, following the Overview, Design and Details (ODD) protocol (Grimm et al. 2006; Grimm et al. 2010), which is presented in Annex B, as is custom with agent-based modelling. Figure 3.1 schematically presents the ABM, which will be further detailed over the following paragraphs.

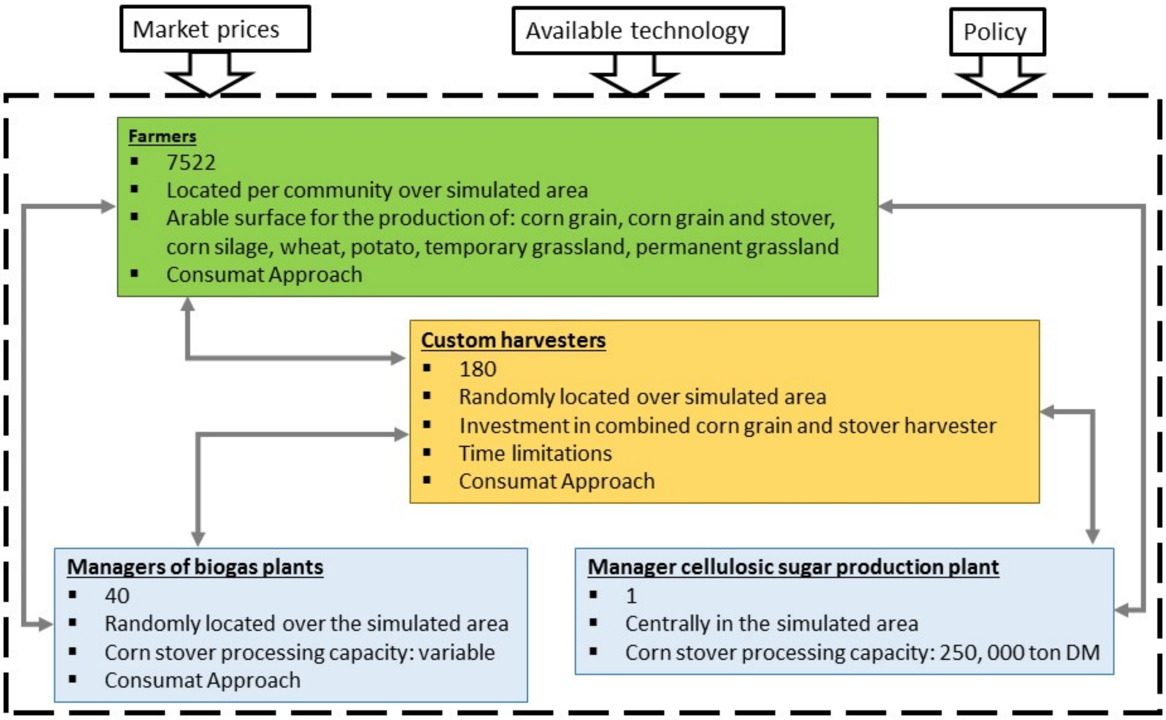


Figure 3.1 Schematic representation of the four agent types included in the model and their main features. The grey arrows represent the interactions between agents. The dashed rectangle shows the model boundary and external factors.

3.2.2.1 Agents

Our model contains four agent types: farmers, custom harvesters (CHs), biogas plant managers and one manager of a cellulosic sugar production plant (CSPP). These agents operate in a simulated environment with the area and shape of Flanders.

First, we included 7522 farmers in the model, equal to the number of farmers growing corn grain in Flanders in 2010. Data for these farmers were retrieved from the Belgian Farm Structure Survey (FOD Economie-Algemene Directie Statistiek 2014). The location of each farmer was provided at municipality level, hence we located each farmer in the municipality center. Each farmer also has some farm land on which he can grow corn grain, corn silage, potatoes, wheat, temporary and permanent grassland. We included these crops in the model, because their cumulative area represents 95% of the total cultivated area cultivated by farmers that grow corn grain (FOD Economie-Algemene Directie Statistiek 2014). Farmers sell their products as price-takers at given market prices, which we obtained from the yearly average crop prices from the period 2003 to 2014 (Figure 3.2) (Wageningen UR 2014; Wageningen UR Livestock Research 2014). At the start of each simulated year, farmers can adjust the proportion of land devoted to each crop included in the model. However, they are limited by crop rotation constraints (e.g. potatoes can only be planted on the same plot every 3 years)[17].

[17] Details on these crop rotation constraints can be found in Annex B

Additionally, farmers can decide to grow a corn variety of which both the grain and the stover can be harvested (e.g. Eleganza), but with a lower yield than the traditional varieties. How farmers decide on their cropping plan decision is explained in section 3.2.2.3.

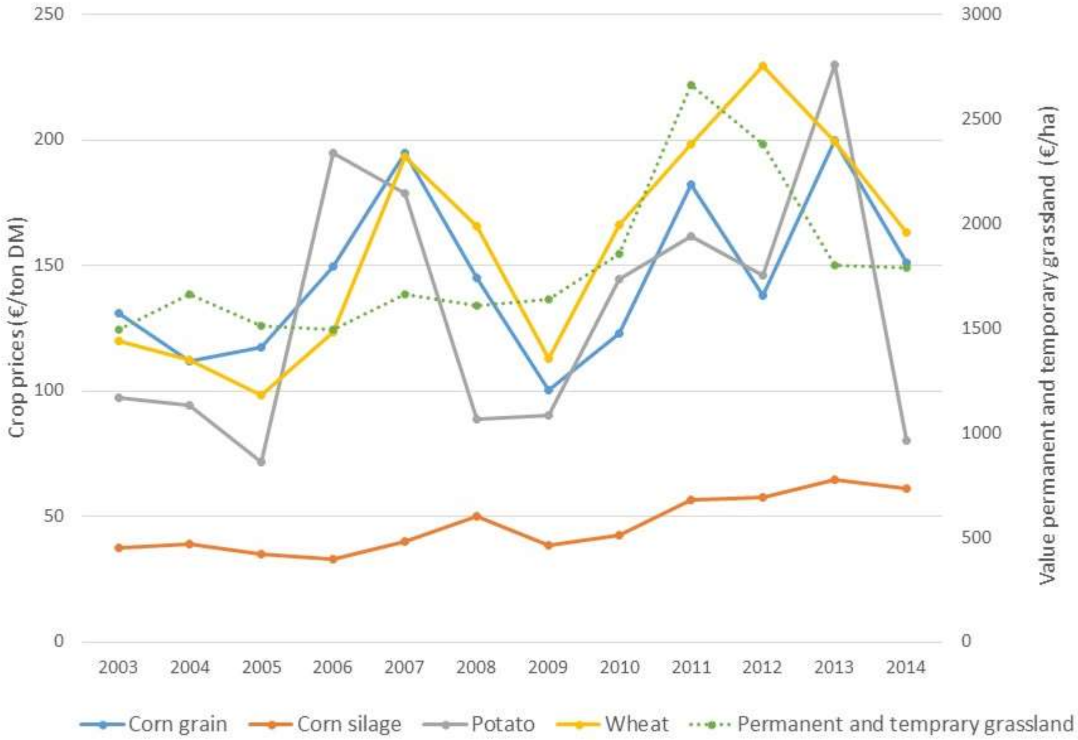


Figure 3.2 Historical prices of crops included in the model. The prices for corn grain, corn silage, potato and wheat are expressed in €/ton DM (left axis). Permanent and temporary grassland profits are expressed in €/ha (right axis).

Next, we included 180 custom harvesters (CHs), responsible for harvesting the farmers' corn grain. Each CH has a random location in the simulated environment and is assumed to own one regular corn grain combine. We assumed, based on interviews with CHs, that with this combine, each CH can harvest maximally 400 hectares of corn grain yearly. In the model, CHs also have the possibility to invest in a single-pass harvester, allowing them to simultaneously harvest corn grain and stover. The grain is collected in the combine, while the chopped stover is collected in a towed forage wagon (Vadas & Digman 2013). As harvesting with such a single-pass harvester is slower than with a regular combine, CHs can only harvest 300 hectares of corn grain and stover yearly. How CHs make this investment decision is explained in section 3.2.2.3.

We also included two processor types in the model: 40 small-scale decentralized biogas plants and one large-scale centralized cellulosic sugar production plant (CSPP). The biogas plants are randomly located over the simulated area. Each biogas plant can convert up to 44051 ton of a feedstock mix into biogas annually (Willeghems & Buysse 2016). In absence of corn stover, this feedstock mix is composed of manure (11013 ton), organic waste (26431 ton) and corn silage (6607 ton) as suggested by (Willeghems & Buysse 2016). The prices of manure and organic waste stay fixed during the simulations. Similar to the farmers, biogas plant managers are price-takers with regard to silage maize (Figure 3.2). Biogas plant managers can also decide to use corn stover as input. How they make their input decisions is explained in section 3.2.2.3. Finally, we modelled one manager of a CSPP, in analogy with (Duffy & Marchand 2013; Marchand 2015). We assumed the CSPP is located in the centre of the simulated area and has a maximum processing capacity of 250,000 ton DM of corn stover annually. In the processing facility, corn stover is converted into cellulosic sugars and lignin by-product (Duffy & Marchand 2013). We assume that the manager aims to purchase the corn stover at the lowest price possible. The corn stover price is endogenous, meaning that it results from the behaviour and interactions of the individual agents in the model.

3.2.2.2 Agents' networks

In the model, agents of the same type (farmers, CHs or biogas plant managers) are linked in two different networks: a close network and a broad network. A farmer's close network contains all farmers within a radius of 10 kilometres. A farmer's broad network contains all farmers within the same agro-ecological region, defined as a zone with uniform soil and climate characteristics (FAO 2002). CHs and biogas plant managers are randomly connected through an Erdös-Renyi network (Peres 2014), in which each agent has a probability of 0.3 to be connected to another agent of the same type. All connected agents are part of the agent's broad network. For each connection, we randomly sampled a weight between 0 and 1, representing the strength of the connection. Links with a weight equal or larger than 0.5 represent the agent's close network. Furthermore, farmers and CHs are connected to each other by means of a harvesting contract. The initial contract between a farmer and a CH at the start of the simulations is based on minimum distance and the available capacity of the CH. Farmers can switch between CHs during the simulations.

3.2.2.3 Agents' decision making using the consumat approach

The decision making rules, followed by the famers, the CHs and the biogas plant managers, are based on the consumat approach, originally described by Jager (2000). In our model, we included an adapted version of this model, inspired by van Duinen *et al.* (2016). The consumat approach can be regarded as a meta-model of human behaviour, integrating an abstraction of expert-theories (Jager 2000), and is based on two assumptions. The first assumption states that people follow a satisfying behaviour instead of always making optimal decisions (Simon 1976). Satisfying behaviour can be attributed to the fact that people are not able to browse through all possible decision options, calculate their outcomes and pick the optimal one every time they need to make a decision (Jager 2000). As a consequence, people tend to repeat certain behaviour as long as it is satisfying. The second assumption states that people observe other people's behaviour and use this information to acquire knowledge on new attractive behaviours (Jager 2000; Endres et al. 2013). Hence, people who are uncertain about what decision to make tend to mimic the behaviour of others.

These two assumptions are translated into two variables. The first variable is economic satisfaction (ES) and the second is uncertainty (U). In our model, ES can be regarded as a proxy for the answer to the question "Am I happy with the gross margin I generated, given my current assets (e.g. arable land or machinery)?". The ES is calculated as the ratio of an agent's actual gross margin (AGM) over his potential gross margin (PGM). A farmer's AGM with n crops is calculated as shown in Equation 3.1, in which $P_{c,t}$ is the price for crop c in year t (€/ton DM), $Y_{i,c}$ is the yield of crop c produced by farmer i (ton DM/ha) C_c the production costs of crop c (€/ha), $S_{i,c,t}$ the surface of crop c grown by farmer i in year t (ha) and ST_i the total arable surface available to farmer i. A farmer's potential gross margin is the maximum gross margin per hectare a farmer can obtain, by optimizing his cropping plan given the current crop prices (described in Annex B). A CH's ES is calculated as shown in Equation 3.2, in which $S_{i,Grain,t}$ is the actual harvested surface of corn grain by CH i (ha), $S_{i,Stover,t}$ is the actual harvested surface of corn stover by CH i (ha), $S_{maxGrain}$ is the maximum surface of corn grain that can be harvested with one combine (ha), HS_{Stover} is the maximum surface of corn grain and stover that can be harvested with the single-pass harvester (ha), P_{Grain} is the harvest price of corn grain (€/ha), P_{Stover} is the harvest price of corn grain and stover (€/ha), C_{Grain} are the variable costs of harvesting corn grain and C_{Stover} are the variable costs of harvesting corn grain and stover. For the biogas plant managers, the AGM is calculated as presented by (Willeghems & Buysse 2016) and shown in Equation 3.3, in which Y_i (m^3 CH_4 / ton,) is the methane yield of product i, ε (MWh/m^3) is a conversion factor, ϕ_{elec} and ϕ_{heat} the relative amount of own electricity and heat consumption respectively, π_{elec} (€/MWhe) and π_{heat} (€/MWhth) the revenue from sale of generated electricity and heat respectively, $\pi_{elec,avoid}$ (€/MWhe) and $\pi_{heat,avoid}$ (€/MWhth) the expenses avoided due to own consumption of electricity and heat respectively, σ_{GEC} (€/ MWhe) and σ_{heat} (€/MWhth) subsidies in the form of green electricity certificates and green heat certificates respectively and $q_{i,t}$ (m^3) the volume of input i at time t. The biogas plant managers' PGM is calculated as the maximum gross margin a biogas plant can obtain by optimizing his feedstock plan given the current input prices (corn silage or corn stover) (described in Annex B).

$$Farmers: AGM_{i,t} = \frac{\sum_{c=1}^{n}((P_{c,t} * Y_{i,c} * S_{i,c,t}) - (C_c * S_{i,c,t}))}{ST_i} \quad \text{(Equation 3.1)}$$

$$CHs: ES_{i,t} = \frac{AGM_{i,t}}{PGM_{i,t}}$$

$$= \frac{(S_{i,Grain,t} * (P_{Grain} - C_{Grain})) + (S_{i,Stover,t} * (P_{Stover} - C_{Stover}))}{(S_{maxGrain} * (P_{Grain} - C_{Grain})) + (S_{maxStover} * (P_{Stover} - C_{Stover}))} \quad \text{(Equation 3.2)}$$

$$\text{Biogas plants}: AGM_{b,t} = \left(\sum_i Q_{i,t} Y_i * \varepsilon\right) * \left[0.35 * \left((1 - \varphi_{elec}) * \pi_{elec} + \sigma_{GEC} + \varphi_{elec} * \pi_{elec,avoid}\right) + 0.5 * \left((1 - \varphi_{heat}) * \pi_{heat} + \sigma_{GHC} + \varphi_{heat} * \pi_{heat,avoid}\right)\right] - \left(115{,}846 + \left(110 * \sum_{i,t} Q_{i,t}\right) - 691.794 - (Q_{i,t} * P_{i,t})\right) \quad \text{(Equation 3.3)}$$

The uncertainty value (U) is a proxy for the answer to the question: “How certain am I that the cropping/ machinery investment decisions I made were good decisions given the average economic performance of the other agents?” The uncertainty value is calculated using Equation 3.4 derived from van Duinen *et al.* (2014), in which AGM_{expt} is the agent’s expected gross margin. The expected gross margin is calculated as a Cobb-Douglas function, in which the discounting factor (DF), randomly ranging between 0.2 and 0.8, represents how much an agent attaches importance to the AGM of the other agents of the same agent type in assessing how well he is doing economically. In Equation 3.4, AGM_{mean} is the mean of the actual gross margin of the other agents of the same agent type (i.e. farmers, CHs, or biogas plants).

$$U_{i,t} = 1 - \frac{AGM_{i,t}}{AGM_{expt,i,t}} = 1 - \frac{AGM_{i,t}}{AGM_{i,t}^{1-DF} * AGM_{mean}^{DF}} \quad \text{(Equation 3.4)}$$

The combination of income satisfaction and uncertainty leads to four behavioural rules (Figure 3.3).

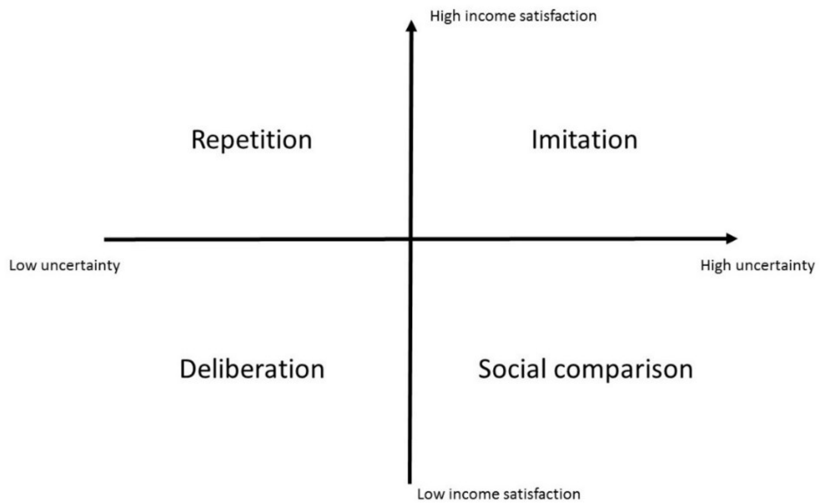


Figure 3.3 Economic satisfaction and uncertainty as included in the consumat approach, leading to four behavioural rules (Figure based on (Jager 2000; van Duinen et al. 2016)**).**

(1) Repetition: applied by agents that are satisfied with their economic performance and certain about the decisions they make. Therefore, they are not inclined to change their behaviour. For farmers, this implies that they keep their current cropping plan, biogas plant managers keep their current input plan and CHs will not consider the option of investing in a new single-pass harvester.

(2) Imitation: applied by agents that are satisfied with their economic performance, but uncertain that their decisions are optimal. Farmers will evaluate the behaviour of farmers in their close network and imitate the cropping plan of the farmer with the highest AGM. We assume imitating CHs will consider purchasing a single-pass harvester if more than half of the CHs in their close network already made the investment. However, they will only invest in a single-pass harvester when they have a contract to harvest that year. Biogas plant managers will copy the input plan of the manager with the highest AGM in their close network.

(3) Social comparison: applied by agents that are unsatisfied from an economic perspective and uncertain about their decisions. Farmers will copy the cropping plan of the farmer with the highest AGM in their broad network. They are assumed to have possibilities for such copying behaviour because farmers' networking days are organized from time to time in which farmers compare their economic performance with other farmers in order to find out if and how they can improve their situation. CHs will consider purchasing a single-pass harvester if more than half of the CHs in their broad network made the investment before. Biogas plant managers will copy the input plan of the manager with the highest AGM in their broad network.

(4) Deliberation: applied by agents who are certain about their decisions but with a low economic satisfaction. Deliberating farmers will optimize their gross margin by optimizing their cropping plan given the current crop prices. Deliberating biogas plant managers will optimize their gross margin by optimizing their input plan given the current input prices. We assume deliberating CHs will consider purchasing a single-pass harvester if the net present value (NPV) of their investment is positive, but they will only invest in a single-pass harvester when they have a contract to harvest that year. Using the NPV allows the CHs to take into account the investments and fixed costs associated with the investment in a single-pass harvester (Equation 3.5).

$$NPV = \sum_{i}^{12} \frac{Potential\ revenue}{(1+p)^i} \qquad \text{(Equation 3.5)}$$

in which p is the discount rate equal to 0.07. In calculating this NPV, the CH relies on the maximum number of hectares he could harvest yearly for a period of 12 years (Potential revenue).

The behavioural rule that each farmer, CH, or biogas plant is most likely to follow, depends on the intersection of the two axes (Figure 3.3). This intersection represents two thresholds and is pre-defined using an aspiration level and uncertainty tolerance, individually set for each farmer, CH or biogas plant manager upon initialization. For the farmers and the CHs, we assumed parameter values 0.5 and standard deviation 0.17 for both the uncertainty value and aspiration level, based on van Duinen *et al* (2016). As the model presented in Duinen *et al.* (2016) does not include biogas plants, we assumed a random value between 0 and 1 for each biogas plant manager for both the uncertainty value and aspiration level.

3.2.3 Modelling corn stover trade

In the model, we assume farmers and processors trade in a corn stover spot market. In this governance structure, farmers interested in selling corn stover individually negotiate with a biogas plant or CSPP manager about the corn stover price, and sell the stover to the processor with the highest bid. Farmers are responsible for the harvest and transport of the corn stover to the processing facility and therefore also bear the costs of these activities. In order for their corn stover to be harvested, farmers need to find a CH that is willing to invest or has already invested in a single-pass harvester. They pay a him a fixed price of 161€/ha to harvest their corn and stover (personal communication with CH).

In order to simulate a negotiation process, trade of corn stover is simulated as a sealed bid auction, repeated 6 times, representing the 6 months period between the planting and the harvest of the corn. In each auction round, processors wanting to purchase stover make a price bid, expressed in €/ton DM, to farmers that want to sell stover:

$$bid_{ji} = Cr * maxWTP_j \qquad \text{(Equation 3.6)}$$

with $maxWTP_j$ the maximum willingness to pay by processor j. We assume that processors are not offering the full maxWTP when they make a bid. Therefore, bids are adjusted in analogy with Shastri *et al.* (2011), by multiplying the maxWTP with a factor Cr:

$$Cr = v^3 \qquad \text{(Equation 3.7)}$$

In determining this Cr, bidders take into account two aspects: (1) the time that remains to be able to purchase the corn stover before the season is over (t) compared to the total time they make offers (T), and (2) the volume of corn stover they were already able to purchase (n) compared to their total demand (N). The parameter v is:

$$v = max[\frac{n}{N}, \frac{t}{T}] \qquad \text{(Equation 3.8)}$$

The bid will be closer to the maxWTP when the processor has a large corn stover deficit or when he is running out of time. The Cr-value is adjusted each auction round. For the CSPP manager the maxWTP is fixed at 129,1 €/ton DM (Duffy & Marchand 2013) or 897 €/ha. The biogas plant managers calculate the maxWTP as:

$$maxWTP_{biogas,t} = \left(\frac{P_{corn\ silage,t}}{Methane\_Yield_{corn\_silage}}\right) * Methane\_Yield_{corn\_stover} \qquad \text{(Equation 3.9)}$$

in which $P_{corn\ silage,\ t}$ is the price of corn silage in year t, $Methane\_Yield_{corn\_silage}$ is fixed at 95m³ CH_4/ton (Willeghems & Buysse 2016) and $Methane\_Yield_{corn\_stover}$ at 85m³ CH_4/ton (De Dobbelaere et al. n.d.). As a result, the maxWTP of the biogas plant managers fluctuates over time. If farmers are not able to sell their stover to the buying agent after 6 auction rounds, they only harvest the corn grain.

After the model was developed, a workshop was organized in which 11 experts were asked to review the model and the initial model results. After the workshop, the model was adjusted based on their comments.

3.2.3.1 Scenarios simulated

In order to gain insight into whether new biomass value chains in areas with smaller scale agriculture should focus on large-scale, centralized processing, small-scale decentralized processing or a combination of these two, we conducted a scenario-analysis including three scenarios:

- **Scenario 1 – Large-scale, centralized processing:** Only the CSPP manager is active in the corn stover value chain. The biogas plant managers rely on other inputs for the production of biogas.
- **Scenario 2 – Small-scale, decentralized processing:** Only biogas plant managers are active in the corn stover value chain. There is no CSPP.
- **Scenario 3 – Competition:** The biogas plant managers and the manager of the CSPP compete for corn stover in the corn stover value chain.

3.3 Results

The results of the simulations, presented below, show the averages and 95% confidence intervals of 100 repetitions for each scenario. We need to stress that the goal of the model is not to simulate reality and generate specific numbers, but rather to gain qualitative insights in corn stover value chain development under different competition scenarios. More specifically, the results explain general corn stover market dynamics given the observed average annual crop prices in Flanders from 2003 to 2014.

Figure 3.4 presents how the results are interlinked with each other: corn stover market dynamics can be influenced by the different decisions and actions of the agents as well as the exogenous parameters (in dashed line boxes). Firstly, farmers' decision to participate is influenced by the prices of the other commodities (Figure 3.2), but also by the corn stover prices offered by the biogas plant managers and the CSPP manager. Next, farmers' participation rate determines the total corn stover supply, and thus whether there is a shortage or abundance of corn stover on the market. Consecutively, this influences how much the biogas plant managers and the CSPP manager are willing to pay for the corn stover. Thus, there is a feedback loop starting with farmers' participation influencing corn stover supply and thus corn stover prices. The prices paid by the processors are constraint by their maxWTP. For the CSPP this is kept fixed over the years. For the biogas plants, the maxWTP depends on the silage maize prices, which can be used as an alternative input (Equation 3.9). Finally, the balance between the corn stover price paid by the biogas plant managers and the CSPP manager determines their competitive position towards each other and the actual corn stover volume each processor can acquire.

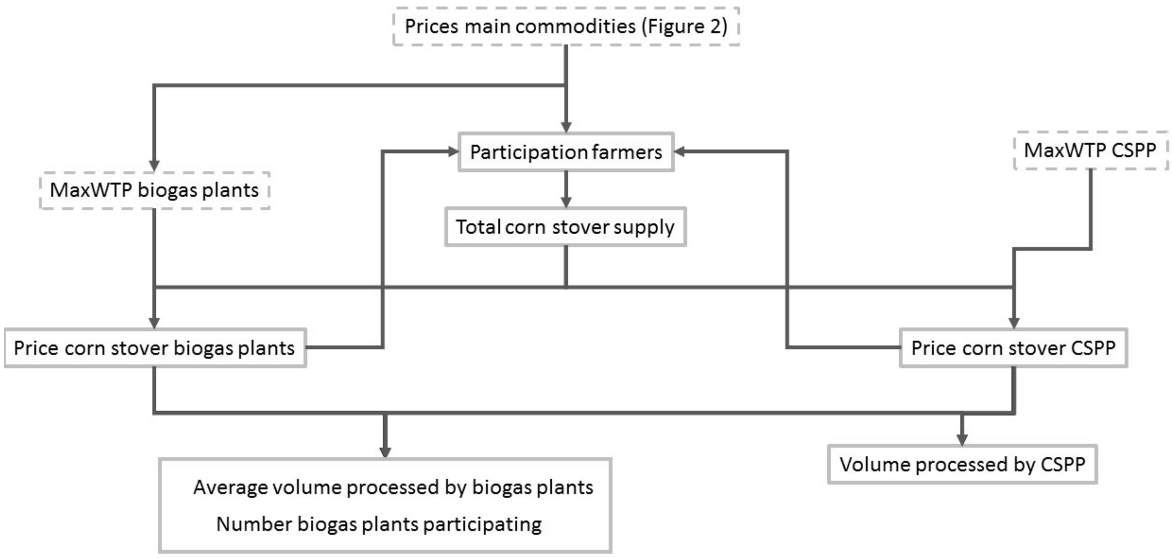


Figure 3.4 Scheme representing model results interactions. The boxes with dashed lines represent exogenous parameter values used as input into the model.

Based on this scheme, the results are presented below. First, we look at the farmers' participation rate, presented in the left pane of Figure 3.5. Overall, large fluctuations can be observed, which are a reaction on the farmers' decisions to change their cropping plan following price fluctuations in the markets of the other commodities, as indicated in Figure 3.4. For example, between year 7 and 10 the share of participating farmers drops to almost 0% for all scenarios. In this period, the prices of wheat, potato and corn grain and the value of grassland all rise significantly. Not achieving the expected revenue and having a low actual gross margin compared to the potential gross margin, farmers become uncertain about their decisions and switch to a social comparison behaviour. As a result, they change their cropping plan in an attempt to make more revenue. Consequently, less farmers decide to participate in the corn stover value chain.

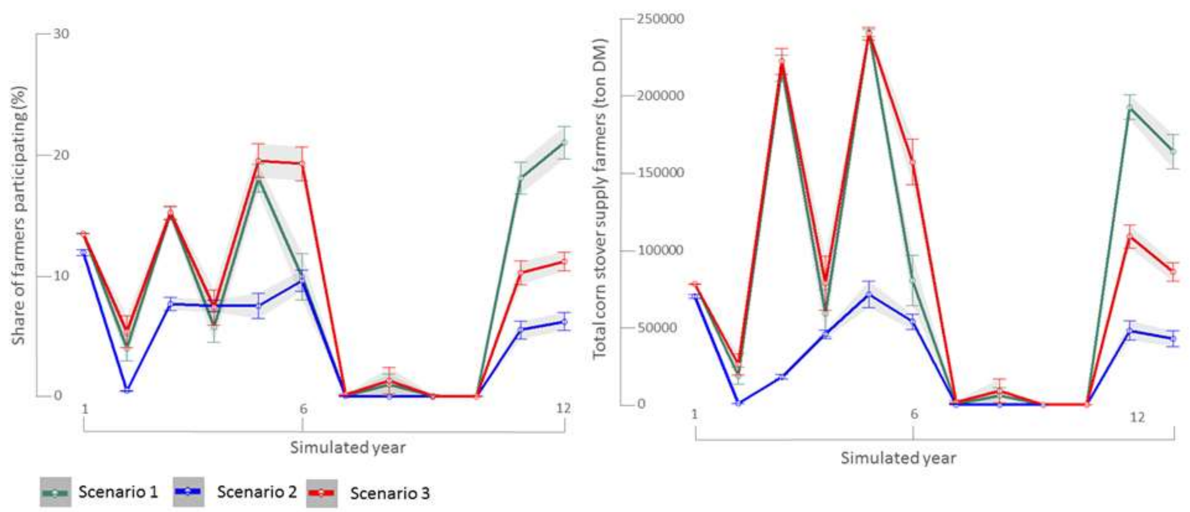


Figure 3.5 Left: Share of farmers participating in the corn stover value chain. Right: Total corn stover volume supply to the market (ton DM). The 95% confidence interval is presented with error bars and in grey.

The fluctuations in the farmers' participation rate lead to a fluctuating corn stover supply (Figure 3.4 and right pane of Figure 3.5).

Comparing the different scenarios, some interesting observations can be made. In years 4, and 7 to 10, there is no significant difference in the number of farmers participating between the different scenarios, nor in the total corn stover supply. In the other years, we observe that when a CSPP is present in the market (Scenario 1 or 3) more farmers participate, resulting in a larger total corn stover supply, than when only biogas plants are active on the market (Scenario 2). Hence, when only the biogas plants are active on the market, only a limited volume of corn stover becomes available, while the presence of a CSPP increases the farmers' participation rate and the total corn stover supply. We found no significant differences between Scenario 1 and 3, except in years 6, 11, and 12. In year 6, only few farmers participate when only the CSPP is active on the market. Furthermore, in this year, more farmers participate and total corn stover supply is higher in case of competition between the two processor types. In years 11 and 12, more farmers participate and total corn stover supply is higher when only the CSPP is active on the market.

The following step in the feedback loop, namely the corn stover prices paid by the two processor types, provides a deeper understanding of the results (Figure 3.4). Figure 3.6 shows the average corn stover prices (€/ha) offered by the biogas plant managers (left pane) and the CSPP manager (right pane). In the first 5 years of the simulated period, the prices offered by the biogas plant managers are lower in absence of competition with the CSPP (Scenario 2). In competition with the CSPP, the biogas plant managers try to attract farmers to sell their stover to them by offering nearly their maxWTP. In years 2, and 7 to 10, the average price offered by the biogas plants in absence of competition only differs little, or does not differ at all from the price in presence of competition. In these years, the number of participating farmers is low for both scenarios, as is the total corn stover supply. As a result of this low supply, biogas plant managers have the incentive to pay higher prices for the corn stover. In year 6, the price remains below the maxWTP in case of competition: the share of participating farmers in this year is high, as is the total corn stover supply. As a result of the abundance of corn stover on the market, prices drop.

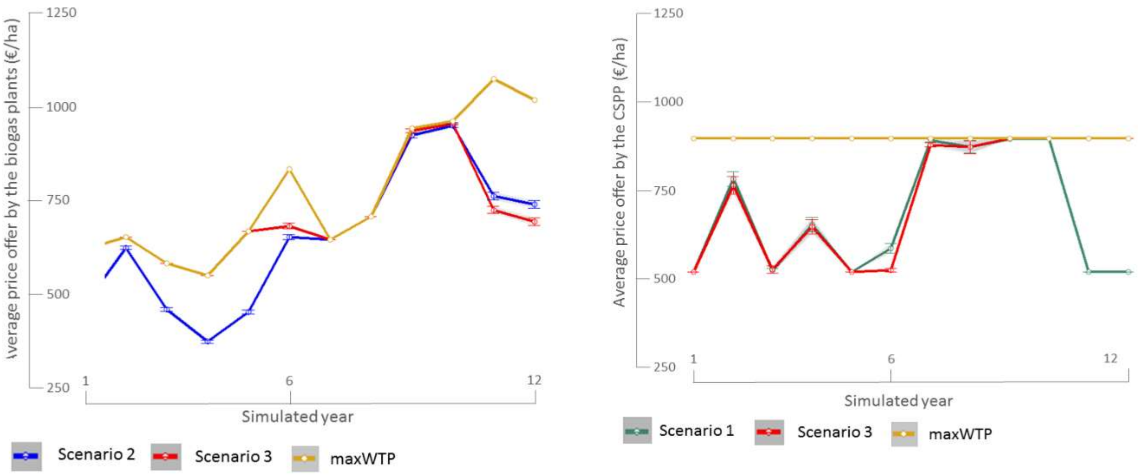


Figure 3.6 Left: Average corn stover price (€/ha) offered by the biogas plant managers. Right: Average corn stover price (€/ha) offered by the CSPP manager. The 95% confidence interval is presented with error bars and in grey.

The prices offered by the CSPP are the result of the same mechanisms (right pane Figure 3.6). For example between year 7 and 10, farmers' participation and the total corn stover supply are low. As a result, the CSPP is willing to offer prices close to the maxWTP in order to still be able to attract sufficient corn stover volumes. In years 11 and 12, more stover is available on the market when only a CSPP is purchasing corn stover compared to the other scenarios, as a result of the higher farmers' participation rate, and the CSPP drops the prices.

Hence, the results show that prices react as expectedly on supply and demand, as was already indicated in Figure 3.4: we observe a price increase in case of low supply and/or high demand and price reductions in case of high supply and/or low demand.

Figure 3.4 illustrates that the balance between the corn stover price paid by the biogas plant managers and the CSPP manager determines their competitive position towards each other, and therefore how much each processor can acquire. Figure 3.7 shows the number of biogas plants participating in the corn stover value chain (left pane) and the average corn stover volume purchased per biogas plant (right pane). Figure 3.8 shows the total corn stover volume processed by the CSPP as a percentage of its maximum capacity (250,000 ton DM). In the first 5 years of the simulations, biogas plant managers are only able to purchase stover in absence of competition with a CSPP (Scenario 2). In presence of a CSPP (Scenario 3), none of the biogas plant managers is able to participate, despite the higher corn prices offered by the biogas plant managers in years 1, 3 and 5. In these years, the difference between the price offered by the CSPP and the biogas plants is not sufficient for farmers to sell their stover to the biogas plants. Starting from year 6, the situation changes. In this year, corn stover prices offered by the biogas plants gradually increase as a result of higher corn silage prices. Therefore, it becomes more interesting for farmers to participate in the corn stover value chain, leading to a higher total corn stover supply in case of competition than in absence of competition with a CSPP. As a result, some biogas plants can participate and attract considerable corn stover volumes, even though they have to compete with the CSPP. Between years 7 and 10, the total corn stover supply is limited and both biogas plant managers as well as the CSPP managers can hardly acquire any corn stover, despite the relatively high prices offered. As corn silage prices further increase over the simulated period, there is a greater incentive for more biogas plants to participate in the corn stover value chain and the prices offered by the biogas plants exceed those offered by the CSPP. In years 11 and 12, more biogas plants participate in case of competition with a CSPP and process on average higher volume. Given the high demand of the biogas plants and the high prices offered to them, in combination with their decentralized position, the biogas plants outcompete the CSPP, which can hardly acquire any corn stover. However, the biogas plants need only a limited amount of stover offered to them. As a result, farmers that want to sell their stover cannot close a deal with their preferred processor during negotiation period and in the end they are not able to sell their stover. This explains why less farmers are participating when there is competition between the two processor types. Moreover, due to the lower transportation costs and the high supply, biogas plants do not need to pay there maxWTP. When only the CSPP is active on the market, this situation does not present itself as farmers can only negotiate with one processor. As a result, more farmers can participate, supplying larger corn stover volumes, leading to lower corn stover prices.

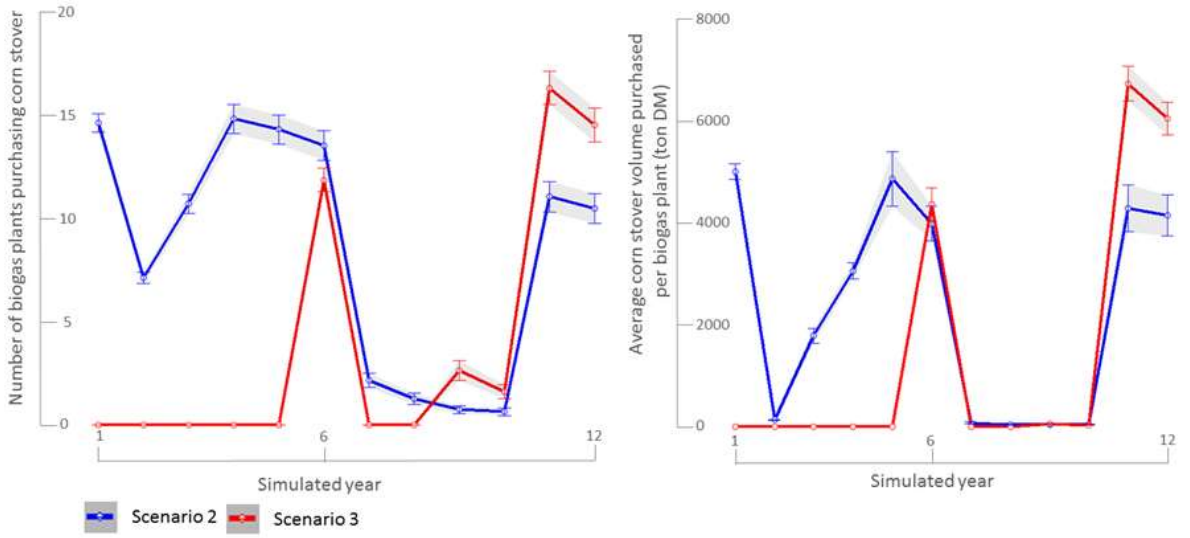


Figure 3.7 Left: Number of biogas plants purchasing corn stover. Right: Average corn stover volume purchased per biogas plant participating in the corn stover value chain (ton DM). The 95% confidence interval is presented with error bars and in grey.

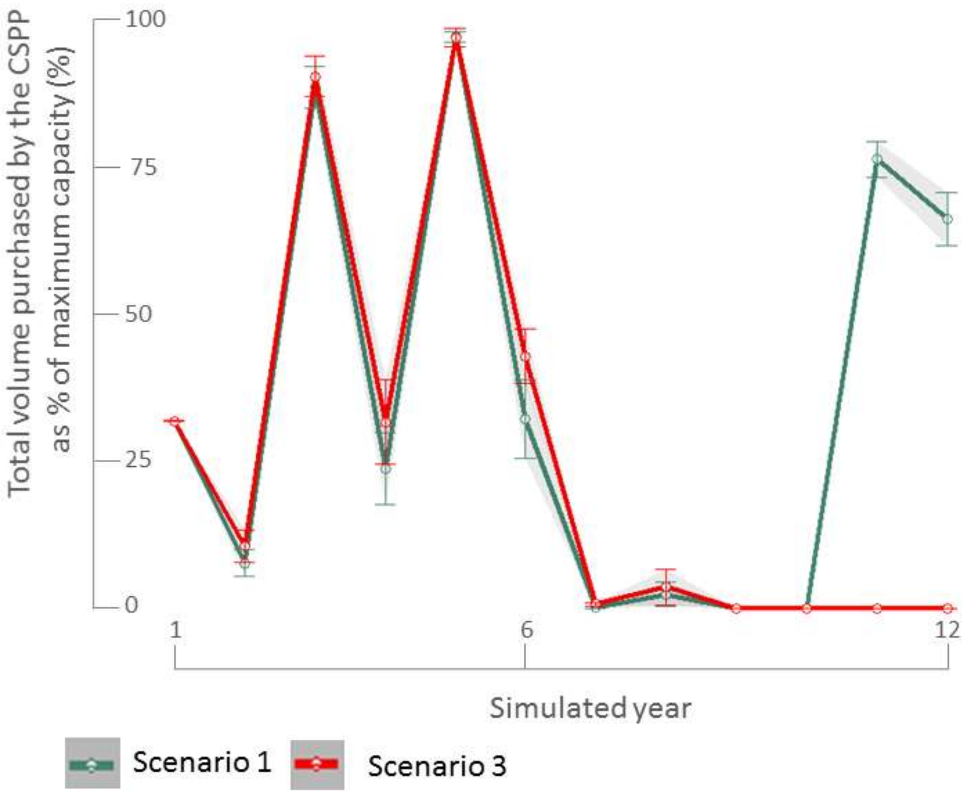


Figure 3.8 Total corn stover volume processed by the CSPP as a percentage of its maximum capacity (250,000 ton DM). The 95% confidence interval is presented with error bars and in grey.

3.4 **Discussion**

3.4.1 Discussion of the model results

The goal of this paper was to investigate the potential of a corn stover value chain for large-scale processing in areas with smaller scale agriculture compared to small-scale decentralized processing. More specifically, we were interested whether competition between large-scale centralized processing and small-scale decentralized processing enhances the development of a corn stover value chain in such regions?

Competition between one centralized large-scale processor and multiple decentralized small-scale processors has a double effect. On the one hand, when competition is manageable, like in year 6, competition can lead to an increased participation of farmers, leading to a higher total corn stover supply on the market. On the other hand, when competition becomes fiercer, due to the increased interest of the biogas plant managers, like in years 11 and 12, competition leads to less farmers participating and a reduced total corn stover supply, while corn stover prices remain relatively high. The biogas plants can more easily acquire a strong competitive position, thanks to their decentralized location and the associated lower transport cases.

Furthermore, from our results, it can be understood that setting up a corn stover value chain will be challenging. For all three scenarios, we found that farmers' participation rate fluctuates, leading to a fluctuating corn stover supply to the market and fluctuating corn stover prices, as a result of variable prices in the different commodities grown by the farmers. Similar price fluctuations were observed for example in the woodchip market in the 1990s (Ministry of Forests, Lands, Natural Resource Operations & Rural Development, 1999) or by other researchers simulating the development of other cellulosic biomass markets, for example Miscanthus (Alexander et al., 2013).

For the biogas plant managers, these market fluctuations have less impact, as they can rely on alternative inputs to produce biogas, including silage maize. However, when only the biogas plants are active on the corn stover market, only a limited number of farmers participates in the corn stover value chain leading to a limited total corn stover supply.

For the CSPP, mostly relying on corn stover, the observed market fluctuations would likely be impossible to bolster over longer periods. Hence, in an area such as Flanders, it does not seem possible to successfully develop a corn stover value chain for large-scale processing under a spot market business model. However, we found that the presence of a large-scale centralized processor increases the number of farmers participating the corn stover value chain and the total corn stover supply. It would therefore be interesting to have such a processor in order to stimulate market development.

We expect that under some conditions market fluctuations could be attenuated. For example, a rise in oil price could for example induce higher prices for bio-based products and therefore be an extra push for corn stover harvest, increasing the maxWTP of the CSPP leading to a more stable farmers' participation rate. Secondly, the processing of biogas to electricity is currently subsidized, while in our model we do not foresee any subsidies for the CSPP. Whether or not a processor receives subsidies changes its maxWTP and could therefore also change its competitive position in the corn stover value chain. Finally, part of the fluctuations observed in farmers' participation rate and corn stover supply result from the governance structure organizing the corn stover trade assumed in the model: a corn stover spot market. A different governance structure might have able to attenuate these fluctuations. This is the subject of future research.

3.4.2 Modelling assumptions

Model results should be interpreted keeping in mind the assumptions made. It was a deliberate choice to leave certain details out of the model, allowing us to foresee sufficient model detail, while still being able to interpret the results. It must be kept in mind that our purpose was not to predict exact outcomes, but to acquire insights in whether competition between one large-scale centralized processor and multiple small-scale decentralized processors could encourage the emergence of a corn stover value chain and yield positive externalities for the stakeholders involved. Our agent-based model contributes to reveal the basic processes that could occur when multiple processors compete for corn stover and we believe following assumptions made are likely to have limited impact on these processes revealed.

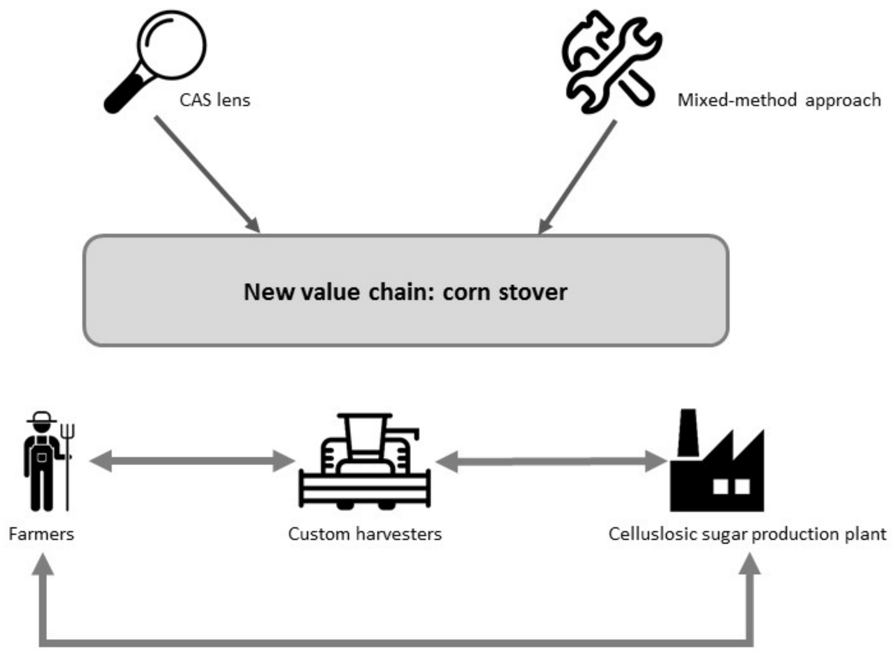
Firstly, we assumed that the land availability remains equal for each farmer over the simulated period. Secondly, we did not take into account inter-year variability of corn stover yields, discussed by (Golecha & Gan 2016), nor of the other crops. Furthermore, we did not take into account the risk of not being able to harvest the corn stover due to extreme wet weather conditions. Also, we took into account prices changes of crops influencing the agents' behaviour, but not of other parameters, such as oil prices. Also, we assumed the uncertainty values and aspiration levels to have an average value of 0.5 and a standard deviation of 0.17 for the farmers and the CHs. For the biogas plant managers, we assumed an aspiration level and an uncertainty value between 0 and 1. Finally, we did not take into account all possible decision parameters of the agents, as this would not only be practically impossible, it would also undermine the interpretability of our results. A detailed description of our model is provided in Annex B to encourage further development of our model.

3.5 Conclusion

In this paper, we present the results from an agent-based model simulating the development of a corn stover value chain in a region with relatively small scale agriculture, namely Flanders, under different competition scenarios. The presence of a large-scale centralized processor, like a cellulosic sugar production plant, mostly relying on corn stover, enhances the development of a corn stover value chain. When only small-scale decentralized biogas plants are active on the corn stover market, the development of the value chain remains limited. Furthermore, the effect of competition is twofold: when competition is manageable, it enhances corn stover value chain development, fierce competition leads to an inefficient market, and a reduced farmers' participation rate and corn stover supply. Furthermore, we found that the decentralized biogas plants can readily acquire a competitive position when stover volumes decrease thanks to their decentralized location and the associated lower transport costs.

Finally, agent-based modelling was found to be a suitable methodology to model the development of a value chain, as it can explicitly take into account the behaviour of the individual economic agents and study the interactions between them. Although assumptions needed to be made, the results provide useful insights in the development of a corn stover value chain under large-scale centralized processing, small-scale decentralized processing and competition. These insights can be used to guide the successful future development of a corn stover value chain in a smaller scale agricultural region like Flanders.

Chapter 4: Governance structures and their impact on the development of a corn stover value chain in Flanders



Specific research question 3: How does the organisation of the corn stover value chain influences its development and market characteristics over time?

In this chapter, we investigate if and how different governance structures influence corn stover value chain development and market characteristics. With our research we are able to demonstrate that by applying a different governance structure, the value chain that develops portrays different characteristics. A direct sale and request-for-purchase scenario have the advantage that economic actors can easily enter and exit the market when they want. However, this also leads to a highly volatile participation rate. As such, investments are likely too risky and large-scale processing of corn stover under these governance structures has little potential. A cooperative governance structure, on the other hand, leads to a more stable corn stover supply. However, this supply remains limited. Furthermore, we find that all stakeholders should be involved when organizing a local biomass value chain. Indeed, we found that the custom harvesters have a central, but at the same time also vulnerable position in the corn stover value chain. Hence, while these agents are often not mentioned in the literature, excluding these agents in the development process of the corn stover value chain will most likely reduce the chances of creating a successful value chain.

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Abstract

Corn stover is a potentially valuable resource for the biobased economy and although interested stakeholders are present, corn stover value chains and markets remain uncommon. One explanation is the knowledge gap on organisational issues along the current research, which is mostly focussing on technological or techno-economic aspects of corn stover harvest and processing. The objective of this paper is to investigate how the governance structure influences the value chain development. Therefore, we use an agent-based model simulating the decisions of three agent types (farmers, custom harvesters and a cellulosic sugar production plant under four governance structure scenarios (direct sale, a custom harvester mediated contract and two cooperative models). The simulation results presented in this article provide useful insights in the differences in market characteristics between non-cooperative and cooperative governance structures, with the cooperative governance structures generating a more stable market. In each scenario, insufficient corn stover was supplied to the processing plant to be able to operate at full capacity. Finally, we demonstrate the central, but vulnerable, role of custom harvesters in the corn stover value chain. Our findings are relevant to guide the successful future development of a corn stover value chain.

Keywords

Corn stover, Biomass supply chains, Bioeconomy, Consumat Approach, Agent-based modelling

This paper is currently under review as:

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4.1 Introduction

In the quest for large volumes of biomass to realise the biobased economy, agricultural residues, such as corn stover, receive increasing attention (IEA-Bioenergy 2015). Over the last decade, a plethora of articles has been published focussing on the technical aspects of corn stover use for feed (Oji et al. 1977; Nennich et al. 2003; Combs 2010; Lascano & Heinrichs 2011; Moreira-Filho et al. 2013), combustion (Bennett et al. 2007; FEL 2009), anaerobic digestion (Schroyen et al. 2014; Song et al. 2014), and the production of bio-ethanol (Eggeman & Elander 2005; Bals et al. 2010). Other research has focussed on the techno-economic aspects of corn stover harvest and logistics (Petrolia 2008; Sokhansanj et al. 2002; Aden & Foust 2009; Hess et al. 2009; Sokhansanj et al. 2010; Babcock et al. 2011; Gan & Smith 2011; Thompson & Tyner 2014), the willingness of farmers to participate in the corn stover value chain (Schechinger & Hettenhaus 2004; Mattison & Norris 2007; Larson et al. 2008; Tyndall et al. 2011; Altman & Sanders 2012; Bergtold et al. 2014) and resource competition. Despite this wealth of information with encouraging research results and interest from different stakeholders, the valorisation of corn stover is still not common practice. For example in Flanders, the northern region of Belgium, a corn stover value chain is practically non-existent. A lack of knowledge on organisational issues, next to the techno-economic challenges, may explain why investments in innovative value chains, such as the corn stover value chain, are held up (Downing et al. 2005; Altman et al. 2007; Altman & Johnson 2008; Altman et al. 2013; Endres et al. 2013; Mafakheri & Nasiri 2014; Weseen et al. 2014). As such, in most techno-economic studies, the governance structure is considered as a black box, and the biomass exchange mechanism is not explicitly taken into account (Bijman 2006; Altman & Johnson 2008).

So far, only a few studies have elaborated on governance structures in biomass supply chains. Altman *et al.* (2012), used survey results to investigate producer preferences for biomass supply chain types that influence market development (Altman & Sanders 2012). Weseen *et al.* (2013) explored the nature of biomass supply chain relations in the western Canadian ethanol sector within the framework of transaction cost economics (Weseen et al. 2014). Endres *et al.* (2013) developed a Biomass Contract Framework providing greater theoretical understanding of biomass supply chain development and of the importance of contract design to facilitate reliable sources of renewable energy (Endres et al. 2013). Recently, Ferrari *et al.* (2016) assessed the effectiveness of a business plan as a tool to manage several uncertainties in new and innovative firms within the context of the biobased economy (Ferrari et al. 2016). These studies address organisational issues, though they remain mainly descriptive, static and use a qualitative approach to assess the influence of different governance structures on the biomass value chain. Nevertheless, it is important to also take into account the innovation diffusion process and market dynamics (Heinimö et al. 2008).

In this study, we explore in a quantitative, prospective and dynamic way whether and how the organisation of the corn stover value chain influences the development and market characteristics over time. We use an agent-based model (ABM), a bottom-up model simulating individual agents forming a complex adaptive system (CAS) through their decisions and interactions. In this context, agents were defined by North and Macal (2007) as “the decision making components in CAS” (North & Macal 2007). CAS were defined by Tesfatsion and Judd (Tesfatsion & Judd 2006) as systems that are “composed of interacting units” and that present emergent properties, which are “properties arising from the interaction of the units that are not properties of the individual units themselves”. In agent-based modelling, the heterogeneous, bounded rational, sociological and strategic decision making aspects of different agents are explicitly recognized (Roos & Rakos 2000). Hence, it allows us to relax some assumptions often taken for granted in other modelling approaches, such as economic rational behaviour or economic equilibria (Hammil & Gilbert 2016).

The ABM presented here simulates interactions between three different stakeholders involved in the corn stover value chain: farmers, custom harvesters and one cellulosic sugar production plant (CSPP) manager. The behavioural rules and decisions leading to the interactions between the agents are modelled explicitly, and derived from the Consumat approach (Jager et al. 2000). The endogenously formed CAS resulting from the agent’s decisions and interactions is the corn stover value chain, developing with its own characteristics, including supply stability, processing capacity, etc. We analyse four governance structure scenarios based on the level of vertical integration, allowing us to discuss a wide range of hybrid structures. More detailed information on ABMs can be found in (Tesfatsion & Judd 2006; Matthews et al. 2007; North & Macal 2007; Borrill & Tesfatsion 2010). We present a case study for Flanders based on available data and expertise, although we believe our results are valid for a wide range of settings.

4.2 General description of the agent-based model

Figure 4.1 schematically presents the ABM. A detailed model description following the Overview, Design and Details (ODD) protocol (Grimm et al. 2006; Grimm et al. 2010) and parameter values are available in Annex C. We developed our ABM in R (R Core Team 2015).

4.2.1 Agents

The model considers three agent types operating in a simulated environment with the area and shape of Flanders: farmers, custom harvesters and one cellulosic sugar production plant (CSPP) manager.

Regarding the processing of the corn stover, we included the CSPP manager in analogy with (Duffy & Marchand 2013; Marchand 2015). We assume that the CSPP is located in the centre of the simulated area and has a maximum yearly processing capacity of 250,000 ton dry matter (DM) of corn stover, similar to the plant described in (Duffy & Marchand 2013). The corn stover is converted into cellulosic sugar and lignin by-product (Duffy & Marchand 2013). We assume that the manager follows a total feedstock cost minimizing behaviour, and aims to purchase the necessary corn stover at the lowest price possible.

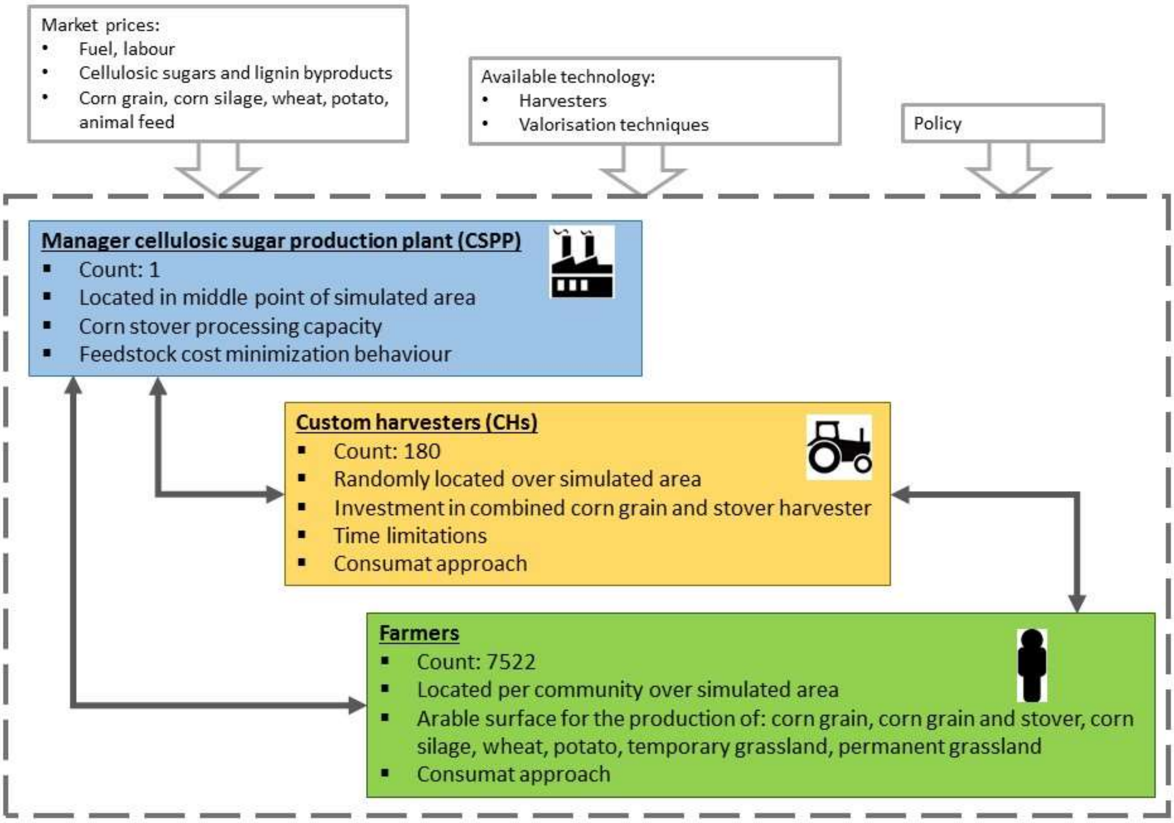


Figure 4.1 Schematic overview of the ABM, showing the three considered agent types and their main features. The dashed rectangle represents the model boundary. Parameters mentioned outside the model boundary (large grey arrows) are derived from literature. Agents' behaviour can be affected by these parameters (e.g. crop prices), but the agents have no influence on their value. The dark grey arrows in two directions represent the possible corn stover trade between the agents, depending on the governance structure simulated.

The model further includes 180 CHs randomly located over the simulated area responsible for harvesting the farmers' corn grain. Interviews done with stakeholders in 2015 revealed that the area that can be harvested with a regular combine is limited. Therefore, we assumed that each CH in the model owns one regular combine and can harvest maximally 400 hectares of corn grain yearly. In the model, CHs also have the possibility to invest in a single-pass harvester, allowing them to simultaneously harvest corn grain and stover. The grain is collected in the combine and the chopped stover in a towed forage wagon (Vadas & Digman 2013). As a single-pass harvester works slower than a regular combine, we assume CHs can only harvest 300 hectares of corn grain and stover yearly. When making investment decisions, we assume the CHs follow the Consumat Approach (Jager et al. 2000) (section 2.2). The initial contract between a farmer and a CH is based on minimum distance and the remaining harvest capacity of the CH. Farmers can switch between CHs during a simulation.

The model further includes 7522 farmers, equal to the number of farmers growing corn grain in 2010 in Flanders. Farm data were retrieved from the Belgian Farm Structure Survey of 2010 (FOD Economie-Algemene Directie Statistiek 2014). The location of the farmers was provided at municipality level, hence we located each farmer in the municipality centre. The farmland area per farmer remained constant during a simulation. Farmers can grow following crops: corn grain, corn silage, potato, wheat, temporary and permanent grassland. These crops were selected representing 95% of the total area cultivated by farmers growing corn grain (FOD Economie-Algemene Directie Statistiek 2014). Farmers are considered to be price-takers: they sell their crops to an exogenous market. We included the yearly average crop prices from 2003 – 2014 (Figure 4.2) (Wageningen UR 2014; Wageningen UR Livestock Research 2014). Farmers can yearly adjust the proportion of land devoted to a certain crop, but are restricted by crop rotation requirements (e.g. potatoes can only be planted on the same plot every 3 years). Additionally, they can decide to grow a corn variety of which both grain and stover can be harvested (e.g. Eleganza). These early varieties have a lower grain yield than the traditional varieties. We assume that farmers follow the Consumat Approach (Jager et al. 2000) to decide on the crop selection and allocation (section 4.2.2).

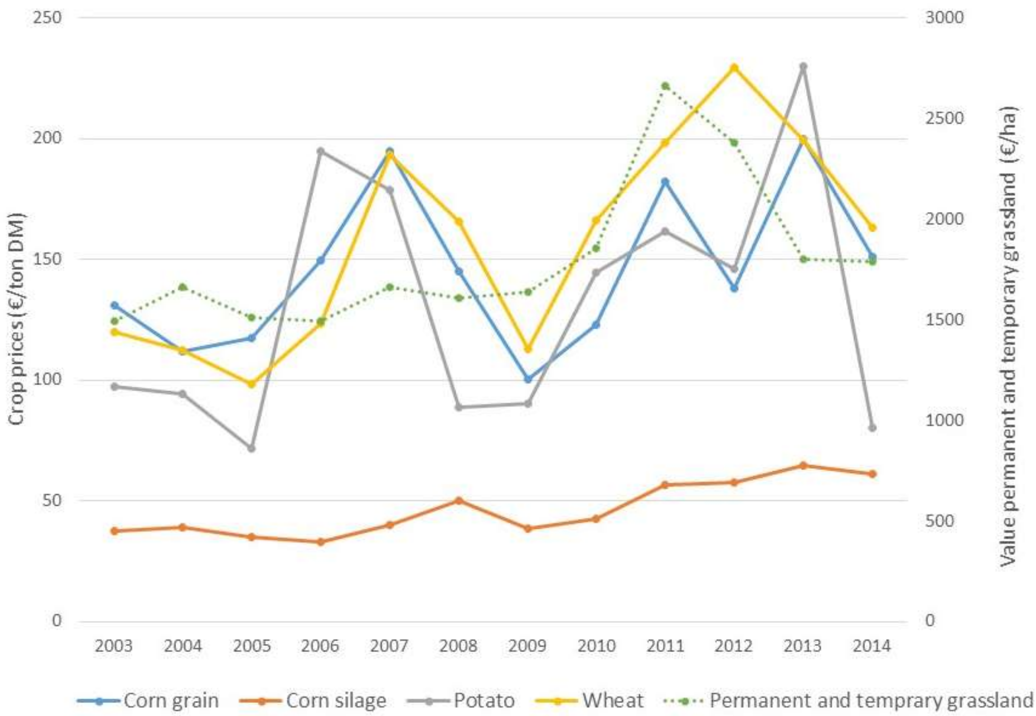


Figure 4.2 Prices of corn grain, corn silage, potato, wheat and grassland included in the model. These prices are expressed in €/ton DM (left y-axis). The values of permanent and temporary grassland (dashed green line) are expressed in €/ha (right y-axis).

We assume that the agents in the model are linked in two network types: a close and a broad one. A farmer's close network contains all farmers within a radius of 10 kilometres. A farmer's broad network contains all farmers within the same agro-ecological region: zones with uniform soil and climate characteristics (FAO 2002). CHs are connected through an Erdös-Renyi network (Peres 2014), in which each agent has a probability of 0.3 to be connected to another CH. All connected agents are part of the broad network. For each connection, we randomly sampled a weight between 0 and 1, representing the strength of the connection. Links with a weight equal or larger than 0.5 represent the close network of an agent.

4.2.2 Consumat Approach

The behavioural rules followed by the CHs and the farmers are based on the Consumat Approach, which is originally described by (Jager et al. 2000). In our model, we included an adapted version based on (van Duinen et al. 2016). The Consumat Approach, a meta-model of human behaviour, integrates insights from expert-theories on human behaviour (Jager et al. 2000). The meta-model is based on two assumptions. Firstly, people follow a satisfying behaviour instead of always making optimal decisions (Simon 1976). This can be attributed to limited time and cognitive resources (Jager et al. 2000), meaning that people are not able to constantly evaluate all possible options and outcomes to determine the optimal decision (Jager et al. 2000). Consequently, people repeat certain behaviours as long as they are satisfied.

Secondly, people observe other people's behaviour and use this information to acquire knowledge on new attractive behaviours (Jager et al. 2000; Endres et al. 2013). Hence, people who are uncertain about their decisions mimic the behaviour of others. According to (Endres et al. 2013), this behaviour is very prominent when decisions are complex and have serious repercussions, such as making large investments to join an innovative value chain.

The Consumat Approach is based on two variables: economic satisfaction (ES) and uncertainty (U). In our model, ES can be regarded as a proxy for "Am I happy with the obtained gross margin, given my current assets (e.g. arable land or machinery)?". The ES is calculated as the ratio of an agent's actual gross margin (AGM) over his potential gross margin (PGM). A farmer's AGM with n crops is calculated as shown in Equation 4.1, in which $P_{c,t}$ is the price for crop c in year t (€/ton DM), $Y_{i,c}$ is the yield of crop c produced by farmer i (ton DM/ha) C_c the production costs of crop c (€/ha), $S_{i,c,t}$ the surface of crop c grown by farmer i in year t (ha) and ST_i the total arable surface available to farmer i. A farmer's potential gross margin is the maximum he can obtain, by optimizing his cropping plan given the current crop prices (described in Annex C). A CH's ES is calculated as shown in Equation 4.2, in which $S_{i,Grain,t}$ is the actual harvested surface of corn grain by CH i (ha), $S_{i,Stover,t}$ is the actual harvested surface of corn stover by CH i (ha), $S_{maxGrain}$ is the maximum surface of corn grain that can be harvested with one combine (ha), $S_{maxStover}$ is the maximum surface of corn grain and stover that can be harvested with the single-pass harvester (ha), P_{Grain} is the harvest price of corn grain (€/ha), P_{Stover} is the harvest price of corn grain and stover (€/ha), C_{Grain} are the variable costs of harvesting corn grain and C_{Stover} are the variable costs of harvesting corn grain and stover.

$$Farmers: AGM_{i,t} = \frac{\sum_{c=1}^{n}((P_{c,t} * Y_{i,c} * S_{i,c,t}) - (C_c * S_{i,c,t}))}{ST_i} \qquad \text{(Equation 4.1)}$$

$$CHs: ES_{i,t} = \frac{AGM_{i,t}}{PGM_{i,t}}$$

$$= \frac{(S_{i,Grain,t} * (P_{Grain} - C_{Grain})) + (S_{i,Stover,t} * (P_{Stover} - C_{Stover}))}{(S_{maxGrain} * (P_{Grain} - C_{Grain})) + (S_{maxStover} * (P_{Stover} - C_{Stover}))} \qquad \text{(Equation 4.2)}$$

The uncertainty value (U) is a proxy for: "How certain am I that my cropping/ machinery investments were good given the average economic performance of the other agents?" The uncertainty value is calculated using Equation 4.3 derived from (van Duinen et al. 2016), in which AGM_{expt} is the agent's expected gross margin. The expected gross margin is calculated as a Cobb-Douglas function. The discounting factor (DF) represents the importance an agent attaches to the AGM of others and varies for each agent between 0.2 and 0.8. In Equation 4.3,

AGM_{mean} is the mean of the actual gross margin of the other agents of the same agent type (i.e. farmers or CHs).

$$U_{i,t} = 1 - \frac{AGM_{i,t}}{AGM_{expt,i,t}} = 1 - \frac{AGM_{i,t}}{{AGM_{i,t}}^{1-DF} * AGM_{mean}^{DF}} \qquad \text{(Equation 4.3)}$$

The combination of income satisfaction and uncertainty leads to four behavioural rules (Figure 4.3).

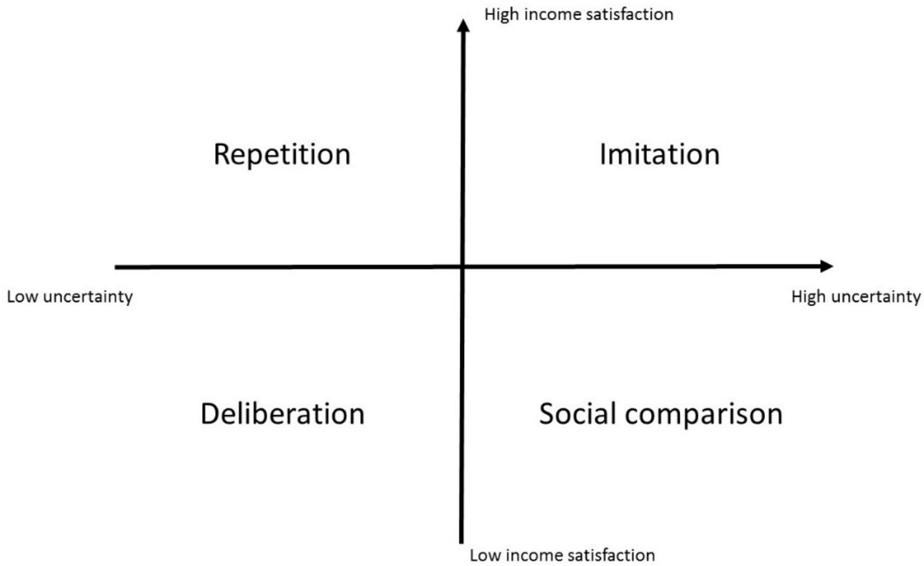


Figure 4.3 Two variables included in the Consumat Approach, leading to four behavioural rules (Figure based on (Jager et al. 2000; van Duinen et al. 2016)**).**

(1) Repetition: applied by agents that are satisfied with their economic performance and certain about the decisions they make. They are not inclined to change their behaviour. Farmers keep their current cropping plan and CHs will not consider investing in a new single-pass harvester.

(2) Imitation: applied by agents that are satisfied with their economic performance, but uncertain about their decisions. Farmers will imitate the cropping plan of the farmer with the highest AGM in their close network. CHs will consider purchasing a single-pass harvester if they have a stover harvesting contract that year and if more than half of the CHs in their close network already did.

(3) Social comparison: applied by agents that are unsatisfied from an economic perspective and uncertain about their decisions. Farmers will copy the cropping plan of the farmer with the highest AGM in their broad network. This behaviour occurs during farmers' networking days focusing on economic performance comparisons in order to identify improvements. CHs will consider purchasing a single-pass harvester if they have a stover harvesting contract that year and if more than half of the CHs in their broad network already did.

(4) Deliberation: applied by agents with a low economic satisfaction who are certain about their decisions. Deliberating farmers will optimize their gross margin by optimizing their cropping plan given current crop prices and crop rotation restrictions. Deliberating CHs will consider purchasing a single-pass harvester if the net present value (NPV) of their investment is positive, but they will only invest if they have a stover harvesting contract that year. The NPV method accounts for investment and fixed costs associated with the investment (Equation 4.4).

$$NPV = \sum_{i}^{12} \frac{Potential\ revenue}{(1+p)^i} \qquad \text{(Equation 4.4)}$$

in which p is the discount rate equal to 0.07. In calculating this NPV, the custom harvester relies on the maximum number of hectares he could harvest yearly for a period of 12 years (Potential revenue)

The behavioural rule that each farmer or CH will follow, depends on the intersection of the two axes (Figure 4.3). This represents two thresholds and is pre-defined using the aspiration level and uncertainty tolerance, individually sampled for each farmer and CH upon model initialization. For both the farmers and the CHs, the uncertainty value and aspiration level are sampled from a normal distribution with a mean value 0.5 and standard deviation 0.17, based on (van Duinen et al. 2016).

4.2.3 Governance structure scenarios

Inspired by (Duffy & Marchand 2013), we included four governance structure scenarios in the model, each representing a different level of vertical integration (Figure 4.4). The first governance structure scenario is a corn stover spot market, called “Direct sale”. In this governance structure, farmers interested in selling stover negotiate individually with the manager of the CSPP about the corn stover price. They are responsible for the harvest and transportation of the stover to the CSPP and also bear the costs of these activities. In order to harvest their corn stover, farmers need to find a CH that is willing to invest or has already invested in a single-pass harvester. In the second governance structure scenario, “Request-for-purchase”, the CHs act as intermediaries between the farmers and the manager of the CSPP. Participating CHs contract a certain volume of stover to be delivered to the CSPP at a certain price. In this case, the CHs are responsible for the harvest and transportation costs and need to look for farmers that want to sell their corn stover. The third governance structure scenario considers a “supply cooperative”, uniting farmers and CHs. The supply cooperative aims to efficiently organise the corn stover harvest and logistics and negotiates as a single entity about the corn stover supply conditions with the manager of the CSPP. Finally, in the fourth governance structure scenario, a “bioprocessing cooperative” is established, associating farmers, CHs and the CSPP. The goal of the bioprocessing coop is to efficiently organise the total corn stover supply chain such that each member shares in the profit made by the CSPP. Detailed information on how these business models are implemented in the ABM can be found in the supplementary ODD protocol.

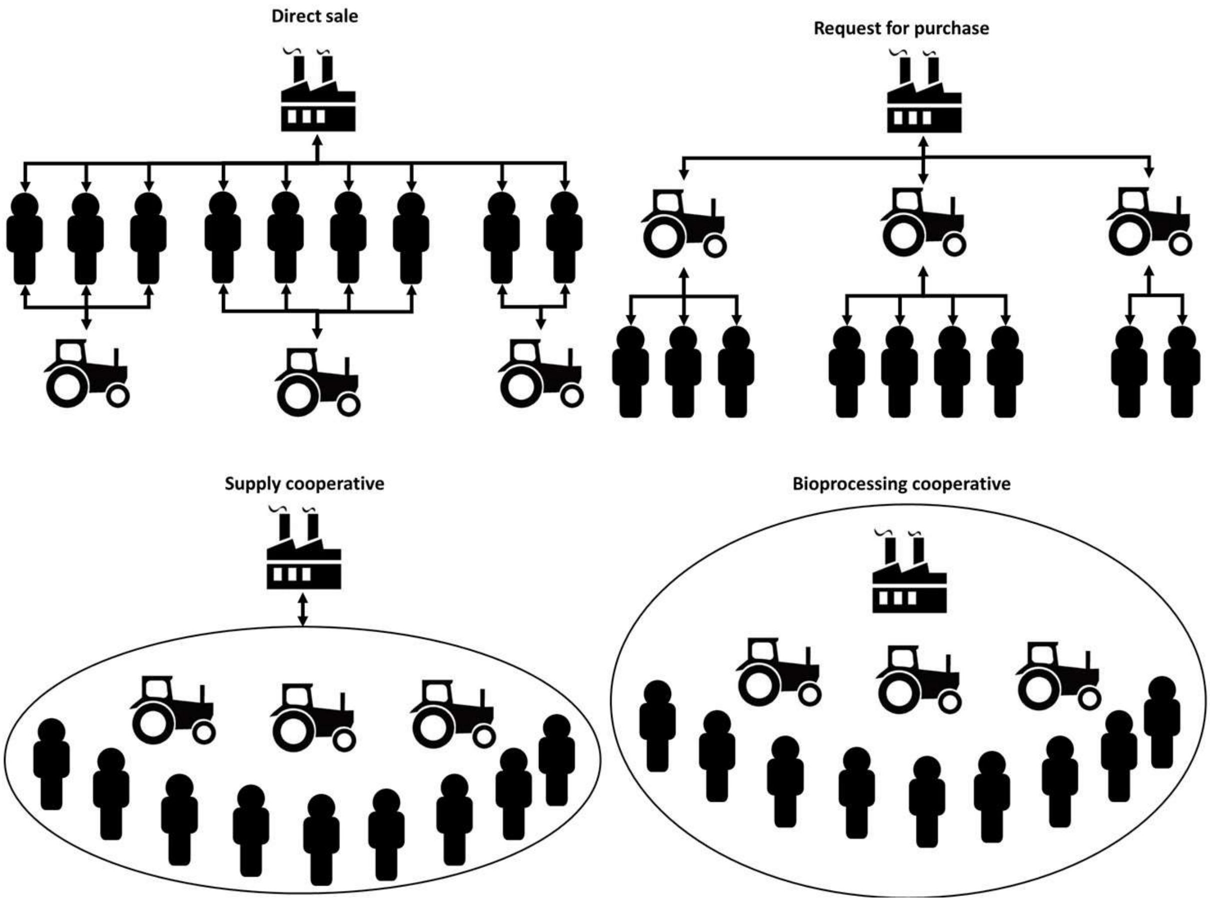


Figure 4.4 Schematic overview of the four governance structures. The manager of the CSPP is represented as a factory, the CHs as tractors and the farmers as persons. Two-sided arrows represent negotiation processes. Circled agents are part of a cooperative.

To evaluate the impact of governance structures on the corn stover value chain development, we selected several performance parameters. A main outcome is the participation rate of both the farmers and the CHs. For the farmers, we looked at the proportion of farmers interested in the corn stover value chain and the proportion that actually participates. For interested farmers, participation in the corn stover value chain is beneficial and they include corn cultivation to harvest both grains and stover in their initial cropping plan. Not all farmers, however, find a CH with remaining capacity or willing to harvest the stover and therefore are excluded from participation in the corn stover value chain. Furthermore, we assessed the stability of the corn stover supply to the CSPP over time. The results are discussed in the next section.

4.3 **Results**

Simulations results are presented as the averages of 100 runs for each governance structure scenario (direct sale, request-for-purchase, supply coop and bioprocessing coop). These repetitions are necessary to capture stochastic effects and to provide general estimations. As the results are influenced by the historic crop prices (2003-2014) included in the model, they are framed in this period. Hence, the section below shows the influence of governance structure on the development of a corn stover value chain in Flanders if a CSPP would have been operational starting from 2003. Due to stochasticity, the model is not suited to forecast exact market behaviour of individual agents. The results should be interpreted in the light of general market dynamics and the development of the corn stover value chain. For all statistical significance tests, we used a Mann-Whitney U test.

4.3.1 Interested versus participating farmers

Figure 4.5 shows, for each of the scenarios, the predicted share of farmers interested to participate in the corn stover value chain (left) and the share that could have actually participated (right) between 2003 and 2014. Overall, the share of interested farmers follows the same trend for the four governance scenarios. In each scenario, it would have started at a relatively high level (48 %), to drop significantly in 2004 to even 0% for the direct sale and request-for-purchase scenarios and to 4% for the cooperative scenarios, and to eventually increase again in 2007 (to 41%, 45%, 50% and 51% for the direct sale, request-for-purchase, supply coop and bioprocessing coop scenarios respectively). For the direct sale and request-for-purchase scenarios, the predicted share of interested farmers drops again to almost 0% from 2009 to 2012. For the cooperative scenarios, this level stays between 8% and 10%. There would be no significant difference in the share of interested farmers between the direct sale and request-for-purchase scenarios between 2009 to 2013. For the same period, the share of interested farmers would have been slightly, but significantly higher ($p < 0.05$) in the bioprocessing coop scenario than in the supply coop scenario. Changes in the prices of other crops grown by the farmers (Figure 4.2), which are the model input data, can explain these fluctuations, as these prices determine the expected revenue. For example, between 2009 and 2012, the share of interested farmers tends to drop significantly. In 2009, the prices of wheat, potato and grain were relatively low. Not achieving the expected revenue, farmers become uncertain about their decisions and switch to a social comparison behaviour. As a result, they would have altered their cropping plan in an attempt to make more revenue. Consequently, fewer farmers would have shown interest in participating in the corn stover value chain.

The predicted share of participating farmers shows a rather capricious pattern in both the direct sale and request-for-purchase scenarios and follows largely the same trend as the share of interested farmers. For the request-for-purchase scenario, this pattern is most pronounced. The cooperative scenarios show a more gradual increase in the share of participating farmers. Starting from 2008, the share of participating farmers in the bioprocessing coop scenario would have been slightly but significantly ($p < 0.05$) higher than in the supply coop scenario.

Remarkably for all scenarios, the predicted share of interested farmer is most often larger than the share of actually participating farmers. This is explained by the behaviour of the CHs, discussed in the next section.

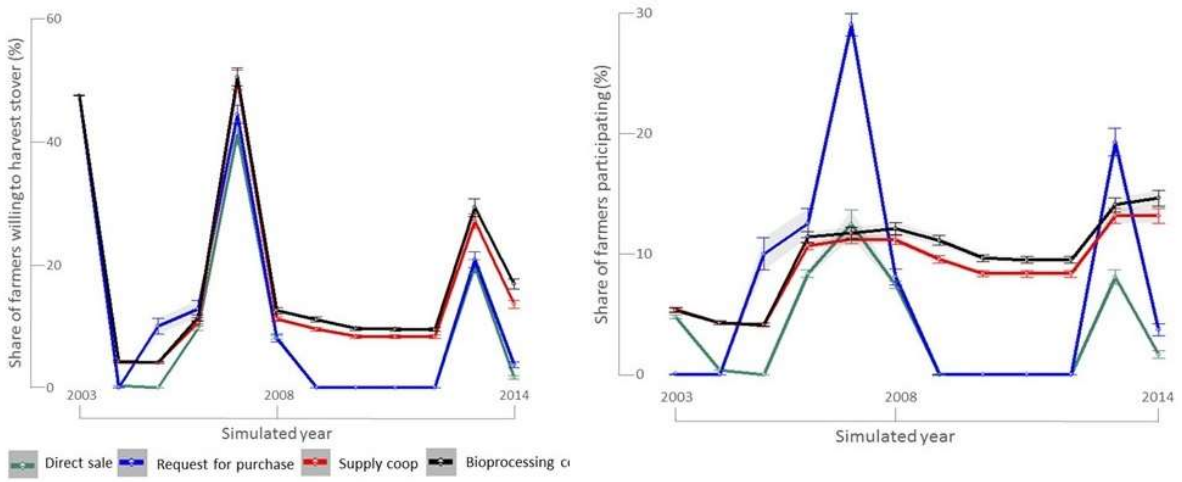


Figure 4.5 Left: Share of farmers interested to participate in the corn stover value chain. Right: Share of farmers actually participating in the corn stover value chain for the four scenarios. The error bars and the grey ribbon represent the 95% confidence interval.

4.3.2 Number of CHs owning a single-pass harvester

The left pane of Figure 4.6 shows the predicted share of CHs owning a single pass harvester. It remains limited to 25% for the direct sale and supply coop scenarios and 27% for the bioprocessing coop scenario. In the request-for-purchase scenario up to 34% of the CHs would have bought a single-pass harvester by 2014. The comparison of Figure 4.6 with Figure 4.5 indicates that the number of single-pass harvesters, each able to harvest 300 hectares per year, limits the number of participating farmers. For example, in 2007 of the bioprocessing scenario, 51% of the farmers would have been interested to participate, which would result in a corn stover harvesting area of about 38,516 ha. Looking at Figure 4.6, we observe that only 22% of the CHs would own a single-pass harvester in 2007, which makes a total harvest of only 11,880 ha. Indeed, in this year and scenario, 12% of the farmers actually participate in the corn stover value chain, which corresponds to an area of 9063 ha of corn planted for the harvest of grains and stover. The difference between the maximal possible surface and the actual surface harvested is explained by limitations in transportation distance and differences in yield between different agro-ecological zones. This result demonstrates the key position of the CHs in the corn stover value chain: a deficit in single-pass harvesters limits the share of farmers that can participate in the value chain and therefore the volumes of corn stover available on the market. Indeed, in the request-for-purchase scenario, the CH has a central position in the value chain, leading to an increased number of CHs owning a single-pass harvester. Due to their central position, CHs are however, also very vulnerable to changes in the market. As the share of participating farmers is dynamic, CHs face a large risk not to be able to fully use their equipment at certain points in time. This overcapacity is presented in the right pane of Figure 4.6, showing the predicted number of single-pass harvesters in surplus given the surface of corn planted for the harvest of both grains and stover. With regard to the direct sale scenario, and even more for the request-for-purchase scenario, we observe a large surplus up to 59 single-pass harvesters between 2008 and 2014. In these years, many CHs will not be able to use their equipment to the full extent or even not at all and their investment will not be profitable. In the supply coop and bioprocessing coop scenarios the surplus remains limited to a maximum of 18 single-pass harvesters. If the share of participating farmers is more stable, as in the cooperative scenarios, the CHs are more likely to use their equipment every year, at least to harvest some hectares.

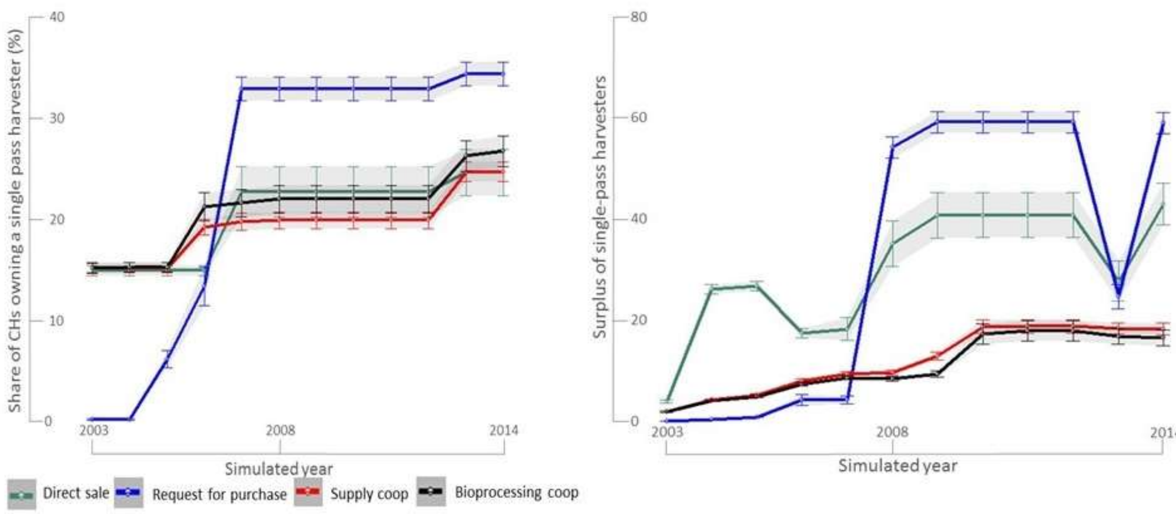


Figure 4.6 Left: Share of CHs owning a single-pass harvester for the four scenarios (%). Right: Actual number of machines in surplus for the surface of corn planted for the harvest of both grains and stover for the four scenarios. The error bars and the grey ribbon represent the 95% confidence interval.

4.3.3 Stover supply and production capacity of the CSPP

Figure 4.7 shows the predicted corn stover volume purchased by the manager of the CSPP as a percentage of the maximum processing capacity of the plant (250,000 ton DM). In fact, this graph illustrates the accumulation of the decisions of both the farmers and the CHs whether or not to participate in the corn stover value chain. The direct sale scenario shows a rather capricious trend, in which supplies would have raised up to about 18% and 12% in 2007 and

2013 respectively, but also would have dropped between 2009 and 2012. The corn stover supply in the request-for-purchase scenario shows a similar trend, only the fluctuations are more pronounced with supply peaks of up to 43% and 29% in 2007 and 2013 respectively. These patterns are in accordance to the predicted share of participating farmers (Figure 4.5). The supply coop and bioprocessing coop scenarios show significantly smaller fluctuations in the corn stover supplies. In the supply coop scenario, the purchased volumes fluctuate between 12% and 19%. For the bioprocessing scenario, these volumes are higher and fluctuate between 17% and 25%. Finally, for all scenarios, we observe that if a CSPP would have been operational in 2003, it could never have acquired the necessary corn stover volumes to operate at full capacity. Indeed, the volumes purchased fluctuate around 20%, which means the CSPP manager could only have acquired a stable supply of about 50,000 ton DM.

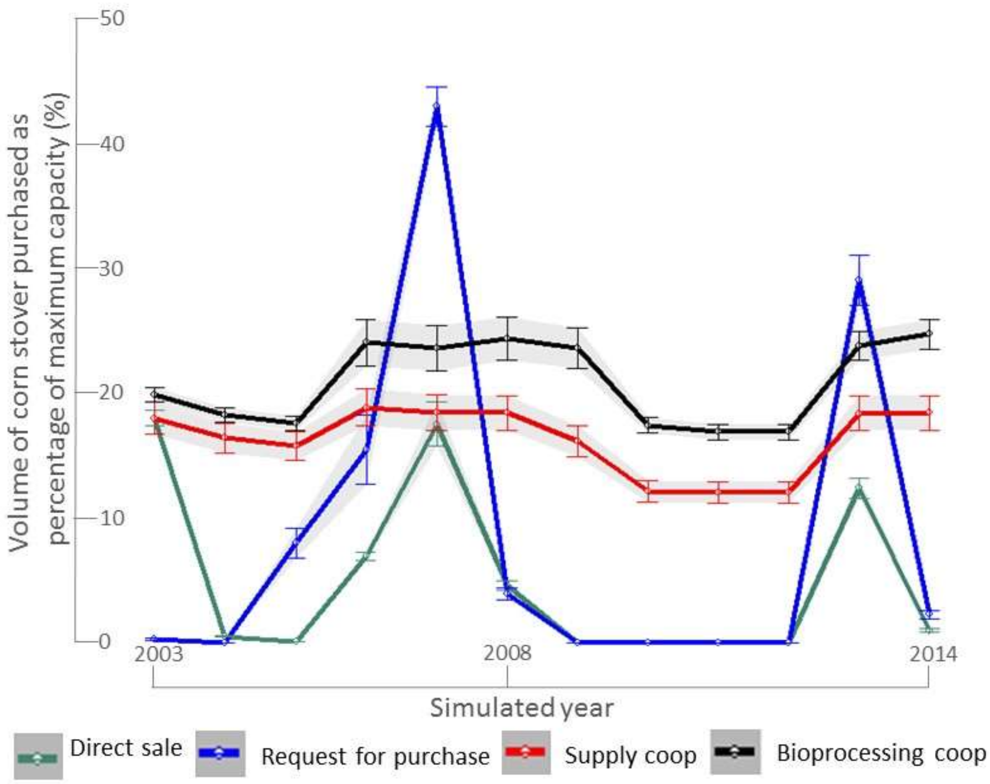


Figure 4.7 Volume of corn stover purchased by the manager of the CSPP as a percentage of the maximum processing capacity for the four governance structures simulated. The error bars and the grey ribbon represent the 95% confidence interval.

4.4 **Discussion**

The discussion is structured as follows: first, we discuss the results and their implications for the corn stover value chain. Next, we discuss the model assumptions and possible venues for further research.

4.4.1 Model results

The purpose of this research was to investigate whether and how the organisation of a corn stover value chain influences its development and market characteristics. Our simulations were done for Flanders assuming that a CSPP would have been operational in 2003. However, more general results can be deducted from our findings, as the initial settings and price fluctuations observed between 2003 and 2014 are not exceptional. Firstly, our results demonstrate that different governance structures lead to a specific corn stover value chain development, each having advantages and disadvantages for each agent type. Simplicity is the main advantage of the direct sale and request-for-purchase scenarios: farmers can easily enter and exit the market whenever they want (Duffy & Marchand 2013). However, when agents need to make large investments, such as the CHs and the CSPP manager, this is a large disadvantage as participation and therefore biomass supply cannot be guaranteed over time (IEA-Bioenergy 2015; Klingenfeld 2008). Our results confirm that the share of participating farmers in these scenarios is largely fluctuating. Farmers' engagement in the market may suddenly drop, leaving the CHs with an expensive single-pass harvester that cannot be used, and the CSPP with an unstable corn stover supply. Therefore, under these governance structures, we believe investments are too risky. Another disadvantage of the direct sale scenario is that the CSPP manager needs to manage separate contracts with hundreds of farmers. Managing such a large number of contracts is often found undesirable by processors (Duffy & Marchand 2013). Additionally, a direct sale scenario may also be unlikely because farmers are not willing to negotiate themselves (Bijman 2006). A request-for-purchase scenario, in which the CHs act as intermediaries between the farmers and the CSPP manager, may partly solve this issue. However, our results still show a largely fluctuating corn stover supply in this governance structure scenario. A major advantage of the cooperative governance structures is the more equal distribution of both profit and risks between the actors involved in the value chain (Duffy & Marchand 2013). Additionally, these governance structures give their members a sense of ownership and profit motivation (Kenkel & Holcomb 2009). Therefore, a more stable and high level stover supply is more likely over time, which was also confirmed by our results. Literature, however, indicates that the additional organisational requirements will also entail additional administration costs (Duffy & Marchand 2013).

Additionally, our results identified an important potential mismatch between the number of farmers and CHs investing in or owning a single-pass harvester.

Irrespectively of the simulated governance structure, we found that a large-scale breakthrough of the cellulosic sugar production only based on corn stover would have been unlikely between 2003 and 2014. Although the corn stover supply in the request-for-purchase scenario reached almost half of the necessary supply at certain points in time, a corn stover supply at this level cannot be maintained over a longer period. For the two cooperative governance structures, the CSPP operation capacity fluctuates around 20% of its maximum. In a region such as Flanders, with relatively small scale farmers and fields, two options exist: to use corn stover in smaller scale processes, producing high value products, or to ensure feedstock flexibility in the CSPP to complement the supply with for example wheat straw, wood chips or miscanthus.

Finally, our results demonstrate the CHs' key, but at the same time vulnerable position in the corn stover value chain. In the literature, their role is often neglected. In agricultural systems where CHs are an intrinsic part of the system, one should recognize their central position and make significant effort to involve them from the start when developing a corn stover value chain (Klingenfeld 2008). In other agricultural systems, without the tradition of working with CHs, their role might expand over time, as the equipment becomes more and more specialized and capital intensive (Tallaksen 2011), as is the case with the single-pass harvester.

4.4.2 Modelling assumptions

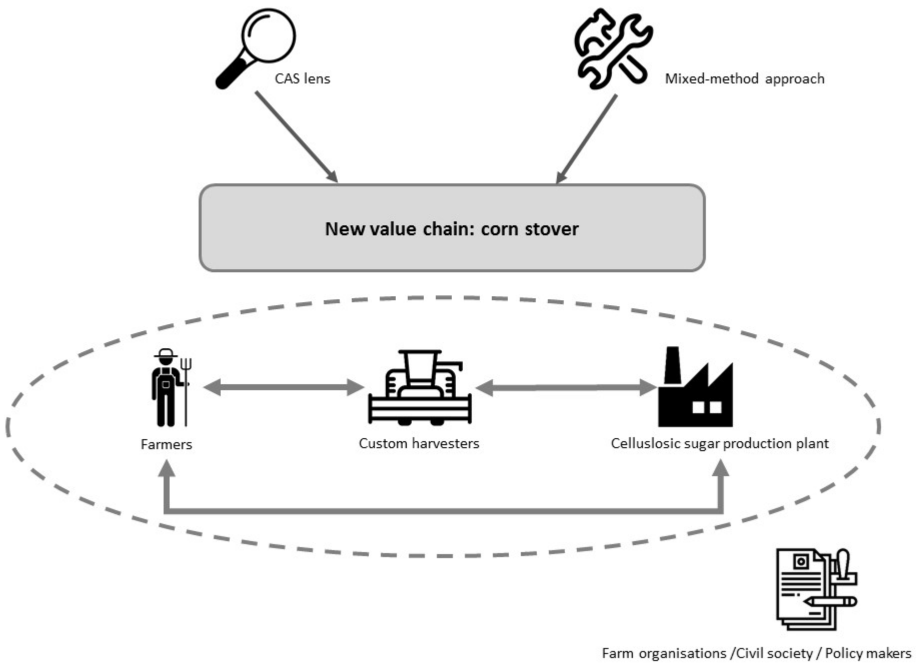
In order to improve confidence in model-based conclusions, it is necessary to assess how model assumptions and parameters alter the results and policy decisions (Willem et al. 2014). On one hand, we might underestimate the development for several reasons. Firstly, we assumed that stover can only be harvested from maize specifically sown for this purpose. In practice, farmers could also decide to harvest the stover of silage maize when the price incentive is large enough. Also the land availability for each farmer can increase or decrease over time. Secondly, we excluded certain economic parameters such as oil prices. A rise in oil prices may, for example, induce higher prices for bio-based products and therefore foster the implementation of the biobased economy. Additionally, we only considered corn stover produced within Flanders and did not consider any import from other regions or countries. This assumption can be argued by the fact that stakeholders indicated that due to the low corn stover density, transportation of this biomass over longer distances than 100 km is not likely to be economically viable. On the other hand, we might overestimate the stover supply since we did not take into account inter-year variability of corn stover yields, discussed by (Golecha & Gan 2016), nor the risk of not being able to harvest the corn stover due to extreme wet weather conditions. In analogy with (van Duinen et al. 2016), we assumed the uncertainty values and aspiration levels to have an average value of 0.5 and a standard deviation of 0.17 for the farmers and the CHs, in analogy with (van Duinen et al. 2016). Nonetheless, a sensitivity analysis, of which the results are discussed in the Annex C, indicated that our main conclusions are still valid in case of certain parameter changes, including the uncertainty values and the aspiration levels. Finally, we did not take into account all possible market mechanisms and governance structures, e.g. long-term contracts. Long-term contracts are however not likely to be the best option in case of cellulosic sugar production, as this would significantly increase the CSPP manager's capital requirements compared to cooperative models (Kenkel & Holcomb 2009), and because it may be difficult to convince farmers to sign such contracts. The selection of governance structure scenarios based on (Duffy & Marchand 2013) and the model detail, was guided by the combination of model complexity to approximate reality, feasibility of parameter estimation and output interpretability. In addition, the model was constructed, not with the aim of producing exact numbers, but in order to gain insights in the mechanisms that determine the effect of different governance structures on the corn stover value chain development. Our results demonstrate the necessity to document the governance structure assumed in future studies of the corn stover value chain. We believe our results are relevant for policy makers and potential stakeholders interested to organise, stimulate or invest in corn stover harvest and/or processing.

4.5 Conclusion

This paper presents the results of an ABM investigating the potential development of a corn stover value chain in Flanders and how the organisation of the value chain influences this development. Firstly, our simulations showed that under none of the considered governance structure scenarios sufficient stover is traded for a CSPP to be able to depend only on corn stover as a feedstock. The reason can be attributed to a limited number of single-pass harvesters available on the market to harvest the corn stover limiting the number of farmers able to participate in the corn stover value chain. Secondly, in case of a direct sale or request-for-purchase scenario, the market shows a rather unstable supply for corn stover. This increases the risk for the CHs not to be able to fully use their single-pass harvester and for the CSPP manager to have a reliable corn stover supply. Both cooperative scenarios show a more stable supply. As the supply in the bioprocessing scenario was significantly higher, this governance structure appears to be the most beneficial. Additionally, our findings demonstrate the central role of CHs in the corn stover value chain. Therefore, we advocate not to forget these crucial stakeholders in future analyses. Finally, our results underline the need to clearly document governance structures in future techno-economic analyses, and at least mention the governance structure assumed in the calculations.

Finally, agent-based modelling was found to be a helpful methodology to analyse a complex system, such as the development of a corn stover value chain. Although many assumptions are needed at various levels of the system, the results provide useful insights in the market characteristics of non-cooperative and cooperative governance structures, with the cooperative governance structures resulting in a more stable market. These insights can be used to guide the successful future development of a corn stover value chain.

Chapter 5: Learning from practice: corn stover value chain development in Ontario



Specific research question 4: What lessons can we learn from corn stover value chains being developed in other regions?

In chapter 5, we present the results of an in-depth case study analysis comparing the development of a corn stover value chain in Flanders and in Ontario. From this analysis we are able to deduce four main success factors that contribute to the successful development of the corn stover value chain in Ontario and shed some light on some of the aspects that hindered its development in Flanders:

(1) <u>Determine the goal of the project</u>: Our analysis confirms the importance of clearly setting the value chain goal. Indeed, the lack of a goal-oriented vision in Flanders seems to hamper engagement by the different stakeholders. In Ontario, the clearly defined project goal enhanced value chain development and proved to be a first step in creating a common vision amongst the different stakeholders.

(2) <u>Consider the whole value chain and actively involve all stakeholders from the start</u>: The analysis demonstrated the importance of a value chain approach, implying that following aspects need to be covered: producers need to be involved to assure sufficient biomass supply, a processor should be involved that can provide a solid technology to make the product wanted, and off-take of the product should be guaranteed. Involving all these stakeholders, creating a common vision and align them in order to create a value chain can be realized by establishing an advisory committee, in which these stakeholders are represented. For this advisory to function properly, a proficient boundary spanning actor is indispensable.

(3) <u>Create trust and enthusiasm amongst all stakeholders in the value chain</u>: Trust and enthusiasm can be created by organizing harvest demonstrations, and working with champions. Furthermore, by having the technology tested and evaluated by the other stakeholders, they gain trust in the technology provider. Additionally, if different stakeholders need to work together and share information, non-disclosure agreements can help in the meanwhile, while trust gradually grows between them. Finally, in order for policy makers to believe in the benefits of value chain being established and not to be deterred by its potential negative impacts, it is important to also involve them in the development process, as this allows them to understand the choices made.

(4) <u>Funding at the right points in time</u>: Although not controlled by the stakeholders directly involved in the corn stover value chain, funding seems crucial in conducting the first necessary studies for corn stover value chain development, before in-kind contributions can be attracted from private companies. Furthermore, while in Flanders subsidies are regarded as indispensable to be able to create an economically viable value chain, in Ontario, the stakeholders consider subsidies as a surplus, rather than a necessary condition.

Abstract

This paper presents the results of an in-depth case study analysis with the aim of identifying success factors in developing an innovative value chain of local biomass for the biobased economy. More particularly, we aim to deduce lessons learnt from a successful case study, being the development of a corn stover value chain in Sarnia-Lambton, Ontario, and compare them with a case study where a corn stover value chain is still being developed, namely Flanders. Applying the integrated analytical framework developed by Lamprinopoulou et al. (2014), we were able to deduce four success factors: (1) determine the goal of the value chain; (2) consider the whole value chain and actively involve all stakeholders; (3) create trust and excitement amongst all stakeholders; and (4) funding at the right moments in time. With this study, we demonstrate the importance of value chain thinking and present a process that can be followed when developing innovative value chains of local biomass for the biobased economy.

Keywords

Integrated analytical framework; corn stover; value chain development; comparative case study

5.1 Introduction

Given the increasing challenges related to the use of fossil fuels, including climate change, the need to use other, more sustainable resources for the production of food, feed, materials and energy is widely accepted. In this respect, the transition of our fossil-based economy towards a biobased economy is often cited as potential solution. As such a biobased economy would need vast amounts of biomass, the biomass resources currently used will not suffice, necessitating the development of new value chains for currently underutilized biomass resources.

Value chains are defined as a “set of interdependent economic activities”, which are undertaken by “a group of vertically linked economic agents” (Bellù 2013). From this definition it is clear that two aspects need to be ensured when developing new value chains. First, the opportunity to carry out the economic activities depends on the availability of adequate technology. As such, technological questions concerning biomass harvest, storage, transport and processing need to be answered. Second, the interlinkages between the economic agents need to be assured by addressing the organisational aspects of the value chain and ensuring that each actor benefits from the value created throughout the chain. Today, many policy documents recognize the need to address these two aspects and call for a value chain approach and (re)configurations of value chains in order to facilitate the development of biorefineries. However, until now, the application of this value chain approach has been limited, and there is little research on how to do this. Therefore, in this paper, we aim to support the application of the value chain approach. More specifically, we aim to identify and elaborate on the success factors of new biomass value chain development in the context of the biobased economy, in which we focus on both the technological as well as the organisational aspects.

In order to realize this objective, we narrow down our focus to corn stover value chain development. Today, large volumes of corn stover are left in the fields after corn grain harvest, making it a good example of an underutilized biomass resource. Corn stover can potentially be used for the production of bioethanol (Eggeman & Elander 2005; Bals et al. 2010) and cellulosic sugars (Duffy & Marchand 2013), as an input for anaerobic digestion (Schroyen et al. 2014; Song et al. 2014), combusted (Bennett et al. 2007; FEL 2009), or as animal feed (Oji et al. 1977; Nennich et al. 2003; Combs 2010; Lascano & Heinrichs 2011; Moreira-Filho et al. 2013). While multiple regions recognize it as an interesting biomass resource for the biobased economy, developing a corn stover value chain has proved to be challenging. Not only does it demand the development of new harvest, storage and processing technologies, it also demands the alignment of previously (or currently) unrelated economic actors, such as farmers and industrial processors.

Through an in-depth analysis of two case studies, we can explore both the technological as well as the organisational aspects relating to corn stover value chain development. The first case study is Flanders, the northern region of Belgium, where several unsuccessful attempts have been made to establish a corn stover value chain. In contrast, in Ontario, Canada, the second case study region, a corn stover value chain is currently being successfully developed. By analysing these two contrasting cases, we aim to amplify the number of factors identified and to deduce the most valuable lessons learnt and policy recommendations necessary to reinvigorate the development of corn stover value chains specifically, and value chains for local biomass in general.

We apply the integrated analytical framework developed by Lamprinopoulou et al. (2014). This framework allows us to both statically evaluate the established value chain in Ontario, and also dynamically assess the process of bringing about this value chain. It integrates several other frameworks “aiming to assess performance of innovation systems and to formulate related policy recommendations” (Lamprinopoulou et al. 2014, p.41). As a result, the framework enables the identification of dynamics between the key structures and functions of innovation systems and between its strengths and weaknesses (Hellsmark et al. 2016). Furthermore, Hellsmark et al. (2016) state that by focusing on the system strengths, one can highlight the realizations of the actors within the system and how policy makers can support it by providing the right environment for the development of actor networks, technologies and institutional structures (Hellsmark et al. 2016).

This paper continues in section 5.2 with an introduction of the two case studies, as well as the integrated analytical framework developed by (Lamprinopoulou et al. 2014). In section 5.3, we present the results of the analysis of the two case studies. In section 5.4, these results are discussed and compared. Furthermore, in this section, we discuss the lessons learnt from the two case studies and some policy implications. Finally, in section 5.5, we present the main conclusions of this research.

5.2 **Methods**

5.2.1 Brief introduction to the case studies

5.2.1.1 Development of a corn stover value chain in Ontario

Since the 1980s, the local chemical industry in Sarnia, a town situated on the shores of Lake Huron in the South region of Ontario, has been in a no growth phase with jobs in decline and it is in need of a new boost. In response, Bio-industrial Innovation Canada (BIC), the Bioeconomy cluster developer, looked for sustainable alternative business opportunities for this town that would make use of the existing infrastructure and local human capital. After a series of studies, it was decided to develop a corn stover value chain producing cellulosic sugars as a central building block for the biobased chemical industry cluster in Sarnia. Coincidentally, the Ontario Federation of Agriculture (OFA) was looking for market opportunities for biomass in the biobased economy and had undertaken producer level studies to determine the optimization of markets.

In the fall of 2012, a meeting was organized between farmers, technology providers, possible end-users, researchers and policy makers to discuss the feasibility of such a project and to explore the opportunities for the region. Later, in the winter of 2012, focus groups were organized for corn producers to express their initial thoughts and concerns. In 2013, an advisory committee was established, consisting of 10 members and 2 observers, with representatives from BIC, local producers and farm organisations, local processors, including representatives from BioAmber and IGPC (Integrated Grain Processors Co-operative), Jungunzlauer, researchers, and policy makers. The committee met every 6 to 8 weeks with the goal of reviewing the progress of the work conducted by BIC and to provide input into the different techno-economic feasibility and logistics studies (e.g. (Duffy & Marchand 2013; Marchand 2015)). Based on these studies, the members decided to establish the Cellulosic Sugar Producers Cooperative (CSPC). As a next step, the researchers at BIC studied different technologies that could economically convert corn stover into cellulosic sugars. In February 2016, the board members of the CSPC selected Comet Biorefining as the preferred technology provider, after an in-depth analysis, evaluation and validation of 19 technology providers on their potential for commercial scale-up applications (CSPC 2017). The CSPC model also created an opportunity for producers to invest in the bioprocessing facility, hence enabling producers to capture a greater share of the benefits from the value chain. In April 2016, Comet Biorefining signed an off-take agreement with BioAmber, a company producing succinic acids using bio-based resources as input, including sugars, instead of fossil fuels. This off-take agreement ensures the sale of the sugars not only to the plant in Sarnia, but also to future BioAmber plants. At the end of 2016, the start of 2017, and the end of 2017, several harvest demonstrations and town hall meetings were organized in order to inform the corn producers in the region about the establishment of the cooperative and to convince them to become members. Comet Biorefining now plans to start the construction of the first commercial cellulosic sugar production plant in Sarnia, which will be located next to the BioAmber plant. The cellulosic sugar production plant, completing the corn stover value chain, should be fully operational in late 2018 or 2019.

5.2.1.2 Development of a corn stover value chain in Flanders

Unlike in Ontario, the development of a corn stover value chain in Flanders is still very much in its infancy. The idea of developing a corn stover value chain started during a project funded by the Flemish Agency for Innovation by Science and Technology, called 'VISIONS'. The goal of the project was "identifying the main organic waste streams and byproducts in Flanders with the ambition to use these products in new value chains" (BBEU n.d.). The researchers concluded that corn stover was one of the largest underutilized biomass sources in Flanders with potential to be used in the biobased economy. Around the same time, the project ARBOR was conducted, funded by the Interreg IVB North West Europe program. Part of this project focused on the use of agricultural residues for bioenergy production. Again, corn stover was found to be a promising biomass resource, especially for anaerobic digestion. The researchers concluded that too many technical difficulties hampered the further development of the value chain. Therefore, they stated that more research was necessary, including looking at other regions to identify technological solutions that could be transferred (De Dobbelaere et al. 2015). Industry also showed an interest in the valorisation of corn stover. In particular, one anaerobic digestion plant manager contracted two custom harvesters to harvest corn stover from different farmers. However, the land was too wet during the harvest, causing compaction and the creation of ruts. The stover was also too wet. Therefore, the custom harvesters decided to stop their activities. Finally, in order to address the challenges observed in the projects and bring together the different experiences, several attempts were made to acquire additional funding. However, each of the project proposals submitted was rejected and corn stover value chain development was cut short.

5.2.2 Integrated analytical framework

We apply the integrated analytical framework developed by Lamprinopoulou et al. (2014), presented in Figure 5.1, to analyse the organisational issues in the two case studies. The technological issues in the two case studies are analysed using thematic analysis (Vaismoradi et al. 2013).

The framework, based on different frameworks developed by other authors, was developed to "assess the performance of innovation systems and to formulate related policy recommendations" (Lamprinopoulou et al. 2014, p.41). The key innovation actors involved in the innovation system are classified according to Arnold and Bell (2001) into one or more of following domains: the research domain, the enterprise domain (i.e. the supply chain actors), the innovation influencers domain (e.g. policy makers, farm associations, etc.) and the intermediary domain (e.g. boundary spanning actors) (Arnold & Bell 2001).

In “Step 1”, the performance of the system and how the key innovation actors contribute to this performance is evaluated using a functional analysis, as described by Bergek et al. (2008) and Hekkert et al. (2007) and linked with the structural analysis (Bergek et al. 2008; Hekkert et al. 2007). They describe seven functions which should be in place for innovation systems to be successful. As such, they allow the identification of the factors driving and hampering innovation. These were complemented by Lamprinopoulou et al. (2014) resulting in the following eight functions: (1) knowledge development; (2) entrepreneurial activities/commercial experimentation; (3) knowledge diffusion/exchange; (4) funding; (5) non-monetary resource mobilization; (6) market formation; (7) guidance of the search; and (8) creation of legitimacy.

Next, a micro-level failure analysis is conducted, by assessing the interactions and roles of the key innovation actors, also taking into account the infrastructure available, capabilities, and the informal and informal rules and regulations.

Finally, a macro-level failure analysis is conducted in which the key innovation actors are linked to four, more overarching “system weaknesses or blocking mechanisms” (Lamprinopoulou et al. 2014, p.42): (1) directionality, (2) demand articulation, (3) policy coordination and (4) reflexivity.

While these micro- and macro-level aspects have been positioned as possible sources of failure, they can also be used to expose the merits of the innovation system (Hellsmark et al. 2016).

Making links between the identification of the actors and the functional analysis (Step 1), the identification of the actors and the micro-level failure analysis (Step 2) and the identification of the actors, the functional analysis, the micro-level failure analysis and the macro-level failure analysis (Step 3), allows us to obtain an in-depth insight into the drivers and barriers of the innovation system considered. From these drivers and barriers we can then identify potential pitfalls and success factors for corn stover value chain development.

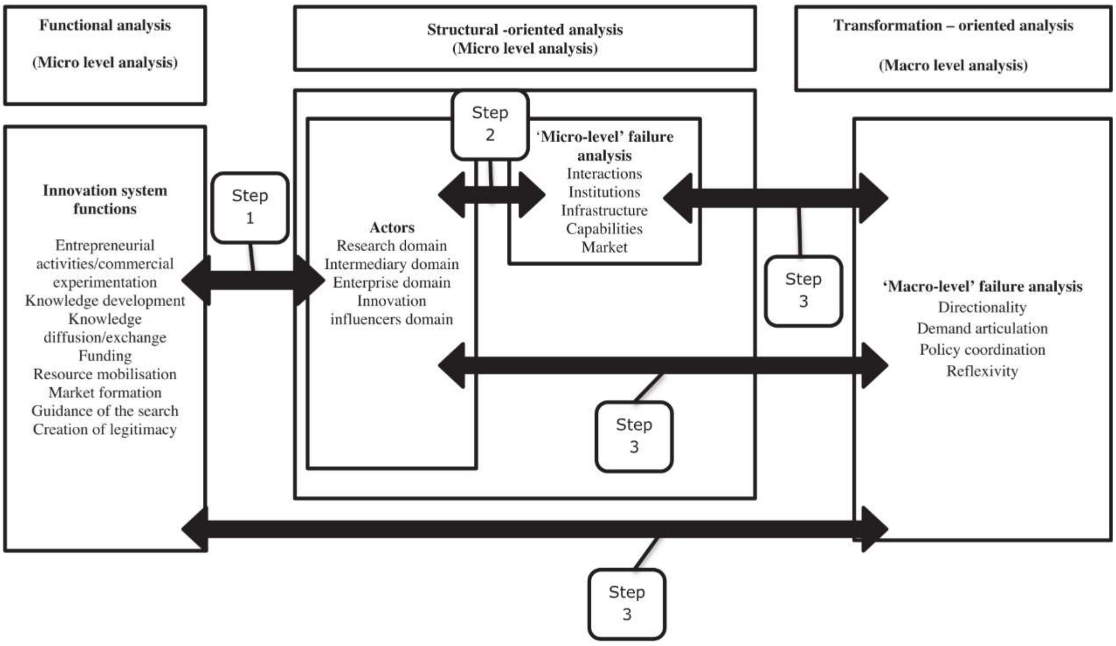


Figure 5.1 Integrated analytical framework. Source: Lamprinopoulou et al. 2014

5.2.3 Data collection and analysis

Qualitative data obtained from semi-structured interviews served as the basis input for the integrated analytical framework. Data collection and analysis was undertaken in three phases (1) data-collection through semi-structured interviews; (2) analysis of the interviews using the integrated analytical framework; and (3) comparison of the two case studies.

In the first phase, we conducted semi-structured interviews with stakeholders involved in one of the two case studies. Questions asked during the semi-structured interviews in both rounds mainly focused on the informants' opinion about the technological and non-technological challenges of corn stover harvest and processing, and how a corn stover value chain could be organized and developed. Data acquired from the interviews was complemented with data from scientific literature, news articles, reports, informal meetings, observations during harvesting demos and on farm shows.

Data collection took place in two rounds. In the first round (March to September 2015), 14 semi-structured interviews were conducted with Flemish stakeholders. As a corn stover value chain in Flanders is virtually non-existent, and only a few respondents had heard of the possibility of corn stover harvest and processing, these respondents were not able to share anecdotes or experiences. Instead, they had to rely on assumptions when speaking about a corn stover value chain. Therefore, it was considered useful to organize a workshop called "*Maïsstro waardevoller dan u denkt*" ("Corn stover, more valuable than you think). During the workshop, the information acquired during the interviews was validated with the participants. In the second round (August and September 2016), 21 semi-structured interviews were conducted with stakeholders involved in the Ontario case study. Here, stakeholders interviewed were well aware of the development of a corn stover value chain, its benefits and challenges and the organisational aspects. Hence, organizing an extra workshop to validate the information gathered was considered unnecessary.

During each data collection round, interviewees were selected as follows. At first, semi-structured interviews were undertaken with experts, selected through a web search based on the organisation they represented and their specific knowledge on the subject. These experts could provide general insights into the subject investigated. Furthermore, these experts also provided names of other experts and other stakeholders, including farmers, custom harvesters and processors, who in turn provided names of new stakeholders. Interviews with these respondents provided more detailed knowledge. When we had the feeling no further information could be acquired by conducting more interviews, the interview round was ended. All semi-structured interviews conducted in these two rounds were recorded and transcribed. This allowed us to transcribe the data and analyse it in NVIVO software using thematic analysis (Vaismoradi et al. 2013).

In the second phase, we applied the integrated analytical framework developed by Lamprinopoulou (2014) to the two case studies. As stated before, this framework only focuses on the organisational aspects of value chain development. The technological issues were identified from the thematic analysis.

In the final phase, we compared the findings of the two case studies in order to deduce lessons learnt and policy recommendations useful for the further promotion of local biomass value chain development, such as corn stover value chains.

5.3 Results

Below, we present the results of the integrated analytical framework applied to the two case studies of corn stover value chain development in Flanders and Ontario. As indicated in the introduction, both technological as well as organisational challenges need to be covered. Hence, below, we first elaborate on the technological aspects of corn stover harvest, storage and processing (section 5.3.1). Next, we discuss the economic actors who were involved in the corn stover value chain development in the two case studies (section 5.3.2). In section 5.3.3 we present the functional analysis and discuss the contribution of the actors to the performance of these functions (Step 1 in Figure 5.1). Finally, in section 5.3.4, we present the results of the micro- and macro-level failure analysis and discuss the links with the actors identified and the functional analysis (Steps 2 and 3 in Figure 5.1)

5.3.1 Technology overview

When developing a corn stover value chain, different technological choices need to be made for the different steps in the supply chain: the harvesting, the storage and the preferred valorisation trajectory. As in Ontario, the corn stover value chain is at a more advanced stage. Therefore, the stakeholders here need to make different technological choices than in Flanders. Furthermore, each region has its own characteristics, leading to different technological preferences, which are further discussed in this section.

5.3.1.1 Harvest system

Over time, several harvest systems for corn stover have been developed, which differ according to the number of passes and how the corn stover will be stored after collection. Vadas and Digman (2013) identified the following possible harvesting systems (Vadas & Digman 2013):

- A three-pass harvest system, whereby the corn grain is combined and the stover is shredded with an adjusted flail chopper that also forms windrows. Next, the stover is collected with a baler or a forage harvester.
- A two-pass system, whereby the corn grain is combined with an adjusted ear-snap header that immediately forms corn stover windrows. Next, the stover is collected with a baler or a forage harvester.
- A single-pass system, whereby either the combine is adjusted at the back so the chopped stover can be immediately collected in a towed forage wagon, or the stover is immediately directed into a baler attached to the back of the combine.

All harvest systems have advantages and disadvantages. Due to some technical challenges in Flanders, it remains uncertain as to what the most beneficial system would be. Indeed, during the harvest period in late fall, the wet fields increase the risk of soil compaction and formation of harvest ruts[18]. Tracks and/or low pressure tires could possibly reduce this risk, but would at the same time greatly increase investment costs. Furthermore, farmers indicated that they dislike different machines passing over their land one after another. Hence, Flemish respondents stated that they would prefer a single-pass harvest system over a multiple-pass system. The single-pass system has several advantages: (1) the stover is harvested without

[18] One strategy to deal with these wet harvest conditions would be to advance the harvest by planting early-harvest corn varieties.

touching the soil, avoiding mud contamination; (2) the total harvest efficiency is increased, as no stover is left on the land; and (3) less labour input is needed.

However, Flemish respondents also acknowledged some disadvantages of the single-pass harvest system: (1) the grain harvest would be slower; (2) a single-pass harvester would be very heavy, increasing the chance of compaction; (3) the small fields (Kerselaers et al. 2015) and roads in Flanders are not fit to accommodate such large machines; and (4) the large investment might not be economically viable if the machine is only suitable for corn stover harvest.

In Ontario, respondents expressed a different view on the choice of the harvest system. In this region, the choice has already been made to harvest the corn stover using a three-pass harvest system for several reasons: (1) the three-pass harvest system has already been used succesfully in the US; (2) farmers have the flexibility to decide when their grains and stover are harvested; (3) the equipment can also be used for other feedstock, such as wheat stover; (4) the stover can stay on the fields a bit longer to dry after the grain harvest; (5) risk of compaction can be addressed by harvesting on frozen fields during spring. The multi-pass system, compared to the single-pass system, has increased the risk of mud contamination. However, as the cooperative is only planning to remove 30% of the stover, only the (non-contaminated) corn stover lying on top will be harvested. Finally, studies done by BIC and OFA showed that single-pass harvest was found to have a higher cost than a multiple-pass system, which does, however, contrast with the findings of Vadas and Digman (2013).

5.3.1.2 Storage system

The technical aspects of corn stover storage also need to be carefully considered, as the stover should be available to the processors 24/7 and year-round.

In Ontario, it has already been decided to press the corn stover into square bales using a specially designed high-density baler. Despite the fact that round bales were found to be easier to produce and less sensitive to water infiltration, square bales are preferred as transportation and storage is more efficient. As the storage at the plant will only be limited, about 30% of the stover will be stored at a storage yard. The corn stover bales stored there will be covered with a plastic tarp to reduce the risk of quality loss and mould formation.

In Flanders, there is insufficient knowledge on how the stover should preferably be stored. One option is to store the stover into square bales. Indeed, square bales are stacked more efficiently, allowing the transport of larger volumes per truck. However, they are more expensive to press compared to round bales, as the process demands more energy.

If the stover is baled, there is a risk of mould formation. Upon harvesting, the stover in Ontario is estimated to have a moisture content of 15.5%. It unlikely this moisture level can be obtained in Flanders. Hence, extra research efforts need to be conducted in Flanders in order to make sure mould formation will be avoided during storage. This risk for mould formation could be reduced by either increasing the bale density or by wrapping them in plastic tarp. Alternatively, the bales could be stored unwrapped but covered with a large plastic film normally used for ensiling.

In Flanders, the option of ensiling the corn stover is also being considered, as many farmers in this region have mastered the technique of ensiling. Furthermore, ensiling could be done on the farmers' land, avoiding the need for extra storage space. However, as the stover contains very little fermentable sugars, the process may require some additives, or the use of early varieties with a good "stay green" characteristic. As such, whether the stover should be ensiled or stored in square bales remains inconclusive and more research is needed to provide more insights.

5.3.1.3 Valorisation trajectory

Finally, before a corn stover value chain can be developed, a decision needs to be made about the targeted end-product. Corn stover has different applications; it can be used as animal bedding or feed, as substrate for mushroom growing, in particle boards, for the production of cellulosic sugars (Duffy & Marchand 2013), or for the production of energy through combustion (Bennett et al. 2007; FEL 2009), anaerobic digestion (Schroyen et al. 2014; Song et al. 2014), and the production of bio-ethanol (Eggeman & Elander 2005; Bals et al. 2010; POET-DSM 2017; Dupont n.d.). In Flanders, there is still ongoing discussion as to which valorisation trajectory would be the most interesting. For example, while some respondents in Flanders showed interest in the use of corn stover as animal bedding or feed, other respondents warned of the presence of mycotoxines. Additionally, the use of corn stover for the production of energy sources does not seem to be very popular amongst the respondents, despite the focus of the different projects on anaerobic digestion. Also the economic feasibility of bio-ethanol production is debatable, as production costs are high but ethanol prices are relatively low. Hence, the production plant should be sufficiently large to achieve economies of scale. However, as such a plant would need almost all the available corn stover in Flanders, this seems almost impossible to realize. Different respondents stressed the need to focus on high-value products, such as sugars, or chemicals. Finally, several respondents highlighted that the contribution of corn stover to the soil organic carbon should not be forgotten.

Again, in Ontario, the perspective on the use of corn stover is different. Here, the construction of the corn stover value chain was initiated on the demand side. Indeed, first it was decided to produce sugars from renewable resources, before it was decided to use corn stover as feedstock.

5.3.2 Actor identification

Identification of the structural components, i.e. the actors, networks and institutions, of the two case studies further allows us to grasp the difference between corn stover value chain development in Flanders and in Ontario. Table 5.1 presents an overview of the main actors involved in both case studies, divided according to the four domains introduced by Arnold and Bell (2001).

As in Flanders, the corn stover value chain is virtually non-existent. Therefore, it is challenging to identify the structural components, which is also acknowledged by Bergek et al. (2008). However, despite the absence of formal networks, by analysing the projects and different attempts to set up a corn stover value chain, we observe that the same group of actors is repeatedly involved. Therefore, in Table 5.1, we call them 'Recurring project partners'. This group of partners can be considered as an informal network that will presumably be brought together again when new funding applications concerning corn stover are submitted. Amongst these actors, we observe that the research domain is mainly covered. To a limited extent, some private actors were also involved at certain points in time, for example, the anaerobic digestion plant manager, who – unsuccessfully – attempted to set up a corn stover value chain by himself. Furthermore, the 'innovation influencers domain' is also barely covered. At a certain point, it was stated that SALV (*Strategic Advisory Board for Agriculture and Fisheries*) would become involved as a member of a planned steering committee. However, as no funding was acquired to set up this steering committee, SALV was never really involved. Finally, during the different applications for funding, it was mainly BioBase Europe Pilot Plant (BBEU) that took the lead and tried to unite all the project partners. However, they were never able to actually take up the role of intermediary partner.

In Ontario, we observe that the actors are more equally balanced over the different domains. Most of these actors were involved in the advisory committee or provided information. Beside a well-established research domain, the enterprise domain is also well-represented. Over the course of the project, these companies were directly involved in different studies, and their advice was taken into account. Furthermore, the innovation influencers' domain was also highly involved; as members of the advisory committee, the policy makers could attend the different discussions and follow up on the progress of the project. Finally, the researchers at BIC positioned themselves as boundary spanning actors. These are individuals or organisations who assist in forming bridges between different organisations that are unaccustomed to working with one another (Smink et al. 2015). In this role, the BIC researchers put a lot of effort into building trust between the different members of the advisory committee.

Table 5.1 Actor identification for the two case studies. Between square brackets we indicate the actors who were involved, but only to a limited extent

Actors	Flanders: Recurring project partners	Ontario: Advisory committee + regular contacts
Research domain	Ghent University, ILVO, Inagro, Ghent Bioeconomy Valley, BioBase Europe Pilot Plant (BBEU), Innovatiesteunpunt	BIC, University of Guelph, Ontario Federation of Agriculture (OFA) Western University, Western Sania-Lambton Research Park, Agriculture and Agri-Food Canada (AAFC), Ontario Agri-Food Technologies, National Research Council Canada, University of British Columbia
Enterprise domain	[Biogas plant manager, custom harvesters, farmers]	Comet Biorefining, BioAmber, Cellulosic Sugar Producers Cooperative, Agco, ProAg, Jungbunzlauer, IGPC, Farmers, Midori Renewables, Lanxess
Innovation influencers' domain	[VLAIO]	OFA, Ontario Ministry of Agriculture, Food and Rural Affairs, Agriculture and Agri-Food Canada, Grain Farmers of Ontario, Agricultural Adaptation Council (AAC)
Intermediary domain	[BBEU]	BIC

5.3.3 Contribution of the actors to fulfilling innovation system functions

Having identified the actors involved within their specific domain, table 5.2 details the contribution of each of these domains to the fulfilment of the different system functions (Step 1 in Figure 5.1).

As most actors involved in Flanders are part of the research domain, it is no surprise that the most time and effort was put into knowledge development. To a limited extent, these actors from the research domain have tried to work together. However, up until now, none of them has been able to take up a coordinating role, assembling the different research results and guiding further research. As a result, the knowledge generated seems to remain somewhat dispersed. Furthermore, as the valorisation trajectory has not yet been defined, it is difficult for the Flemish researchers to guide their research towards the development of a specific value chain. Apart from knowledge development, the other functions are barely addressed or even not covered at all. This lack of coordination of knowledge development and the limited attention paid to the other functions can mainly be attributed to a lack of funding, which will be discussed in more detail in section 5.3.4.3.

We observe a completely different situation in Ontario. Here, almost all the functions are addressed and actors from all domains are highly involved in addressing these functions. The system greatly benefited from the establishment of the advisory committee, involving all stakeholders, and the boundary spanning role taken up by BIC. Furthermore, the project had a clear focus from the start, being the creation of new business opportunities for Sarnia through the production of cellulosic sugars from local biomass sources. Hence, even at an early stage of the project, it was clear to all partners, including the entrepreneurial domain, where the project was headed, and how these private partners could profit from the value chain. As a result, data, feedback and in-kind contributions were more easily obtained.

Table 5.2 Innovation system functions in the two case studies (RD = research domain, ED = enterprise domain, IID = innovation influencers domain, and ID = intermediary domain)

Function	Flanders	Ontario
F1 - Knowledge development	RD: Mainly scientific research with a focus on technical aspects: stover availability; harvest system; potential for anaerobic digestion; effect of removal on soil quality. Some research on socio-economic aspects.	RD: Different studies conducted, first focusing on technical aspects: corn stover availability; harvest system; effect of removal on soil quality. Later also studies on socio-economic aspects, logistics, and governance structures. ED: Different companies provided input data for the studies, and gave feedback on the results. The project partners also learned from the experiences of other corn stover value chains being developed in the United States. IID: Different farmer associations were either directly conducting the studies, or asked to provide input and feedback on the studies conducted. ID: The advisory committee gave feedback on the studies and determined which other studies needed to be conducted.
F2 - Entrepreneurial activities/ commercial experimentation	ED: Some smaller experiments on corn stover storage. One – unsuccessful – attempt by biogas plant manager to set up value chain for his plant.	ED: Project deliberately only worked with companies that already had a functioning pilot plant. Assessing who would be the most suitable for corn stover processing was performed by potential off-takers of the sugars produced.

F3 - Knowledge diffusion/exchange	RD: The different projects have published different reports. Some harvesting demonstrations were organized to show farmers and other stakeholders the possible harvest systems available	RD: Reports of the different studies published. Harvesting demonstrations were organized at well-attended farm shows. Videos on the project were put online. ED: Industrial partners were informed of the results of the studies and asked for feedback. IID: Policy makers were informed of the results of the different studies and asked for feedback. ID: Assembling knowledge and knowledge diffusion by BIC and OFA.
F4 - Funding	RD: Research on the potential of a corn stover value chain was integrated in some European projects PhD research on potential of a corn stover value chain from a socio-economic perspective and the effects of corn stover on soil quality ED: Difficulties experienced in acquiring in-kind contributions IID: No funding sources available that address formation of whole value chains. Little interest from policy makers to fund projects related to the development of a corn stover value chain. ID: No funding was acquired for one partner to take up the role of intermediary organisation.	RD: BIC, OFA and AAFC devoted part of their funding to conducting research on different aspects related to corn stover value chain development. ED: In-kind contributions from different companies. IID: Policy makers notified the partners of different funding opportunities and justified acquired funding from Agricultural Adaptation Council to be managed by BIC ID: BIC devoted part of its funding to act as boundary spanning actor.
F5 - Non-monetary resource mobilization	RD: Researchers have the right competences to bring together information for a corn stover value chain to be developed. ED: Flanders has infrastructure and skilled workforce. Farmers and processors show interest, but refrain from taking further actions.	RD: Researchers have the right competences to bring together information for a corn stover value chain to be developed. ED: Sarnia is a chemical hub with available knowledge, skilled workforce and infrastructure, surrounded by agricultural land ID: BIC is proficient as intermediary organisation

F6 - Market formation	RD: Little research on corn stover value chain development from a socio-economic perspective. ED: No knowledge of specific actions to support market formation at this stage. There is no clear demand profile from the farmers: they show interest because of the additional income, but no clear sign that they would want to become part of the value chain. Anaerobic digestion plant managers or particle board producers show interest, but refrain from taking actions.	RD: Research on governance structures and other socio-economic questions. ED: Clear demand profile from the farmers to have their stover harvested and to participate in the corn stover value chain, resulting in the CSPC. Discussions between CSPC and Comet Biorefining have led to a corn stover price that is acceptable for both sides. Off-take agreements are signed between Comet Biorefining and BioAmber. ID: BIC established an advisory committee and helped with the formation of a market. They also helped to find members for the CSPC by organizing different town hall meetings.
F7 - Guidance of the search	RD: Research is being conducted in different institutes, but not in a coordinated way. ED: No real consensus yet on preferred valorisation trajectory. IID: Farmer associations are following up on the research being done, but take no further actions. Policy makers are potentially interested from the perspective of further developing the bioeconomy and biobased economy. ID: No advisory board was set up to guide the further development of the value chain	RD: Research was directed towards the production of cellulosic sugars from corn stover. ED: Different stakeholders in the value chain all worked together through an advisory committee IID: Farmer associations are following up on the research being done on corn stover, and provide input and feedback on the studies conducted. Policy makers are interested from the perspective of further developing the bioeconomy and biobased economy. Value chain helps in creating new business opportunities for Sarnia. ID: Common vision amongst the stakeholders created through advisory committee.
F8 - Creation of legitimacy	RD: Organisation of harvesting demonstrations. ED: Avoid food-vs-fuel debate	RD: Organisation of harvesting demonstrations, conducting studies on the effects of corn stover harvest on soil quality, detailed studies on the economics and logistics of the corn stover value chain. ED: Testing of technology provided by Comet Biorefining created trust in the technology with the potential off-takers of the sugars.

		Working with champions to create trust and convince farmers to engage in the CSPC. Strict rules set up by CSPC to ensure sustainability and avoid deterioration of soil quality. Avoid food-vs-fuel debate IID: Increased legitimacy by involvement of policy from the start.
F9 - Formation of social capital	ID: No knowledge of specific actions to create trust between the different stakeholders.	ID: Clear role taken up by BIC to create trust amongst the different stakeholders. Trust was gradually being built up, first letting stakeholders sign non-disclosure agreements.

5.3.4 Systemic structural and transformational failures and merits

After identifying the different actors involved and how they contribute to the fulfilment of the different system functions, in this section we discuss how this leads to systemic structural and transformational failures and merits (Steps 2 and 3 in Figure 5.1).

5.3.4.1 Knowledge infrastructure and capabilities

Both in Flanders and Ontario, knowledge infrastructure is well developed, allowing e.g. technology testing both at laboratory as well as at pilot scale. In both case studies, there is a high concentration of universities and research institutes that are used collaborating. Furthermore, they seem to have a good relationship with different interest groups, including farmer's organisations. Thanks to the establishment of the advisory committee in Ontario, farmer's organisations and policy makers have been involved more closely, more formally, and earlier in the project than in Flanders. As a result, their knowledge, advice and feedback were also integrated from the start, which proved to be an asset in the value chain development.

In both case studies, the necessary human capital is also available for the development of a corn stover value chain. For example in Flanders, thanks to the Flanders Bioeconomy Valley and the Port of Antwerp, sufficient knowledge and a skilled workforce are available. In Ontario, with Sarnia as a chemical hub, knowledge and a skilled workforce are also widely present.

5.3.4.2 Physical infrastructure

Physical infrastructure in the two case studies differs significantly.

Firstly, farms in Flanders are generally relatively small, with the average farmer cultivating about 25 hectares of land (FOD Economie-Algemene Directie Statistiek 2017). Hence, a large-scale corn stover processing unit would need to collect its inputs from a large number of farmers. Additionally, fields in Flanders are generally quite small. Indeed, Kerselaers et al. (2015) stated that the median area is about 1.1 ha and “only 12% of the parcels is larger than 3 ha” (Kerselaers et al. 2015, p.211). As already stated, such fields are not fit to host large harvesting equipment. Moreover, small roads and frequent traffic jams make transportation even more cumbersome and expensive. These specific characteristics increase the logistical challenges in organizing the value chain. On the other hand, Flanders has well-developed industrial zones which could potentially host a large-scale corn stover processing plant, including the Port of Antwerp and Ghent Bioeconomy Valley. Furthermore, thanks to the relative closeness of these industrial zones transportation costs would remain limited.

The situation in Ontario is quite different. As one respondent stated: *“That is a perfect model, if you can find a place where it works. And we are really lucky that we got all the farmers right around the chemical plants.”* (Researcher). It is a combination of characteristics that makes Sarnia an almost perfect location to develop a corn stover value chain. Firstly, Sarnia is surrounded by a large agricultural area, where most farmers grow a wheat-corn-soybean rotation. In this area, the counties of Chatham-Kent, Middlesex, Lambton and Huron, are those where the sustainable removal rates are the highest in the whole of Ontario (Kludze et al. 2013). According to the respondents, the average farmer cultivates between 1000 and 5000 hectares of land[19], which implies a relatively limited number of farmers is required to collect a critical volume of corn stover in order to make large-scale processing possible. They further indicated that average field sizes are between 30 and 40 hectares, which allows for more efficient harvesting using larger equipment. Hence, sufficient corn stover is relatively readily available and nearby. Furthermore, Sarnia already has a well-developed petro-chemical industry located in a large industrial zone. This means the right infrastructure is already available for the production of chemical products, for transportation over land and water, as well as railroads, and access to off-grid power. As one farmer and board member of the CSPC stated: “*All the utilities are already there. They just have to connect into them”.* Finally, the BioAmber plant is also located in Sarnia, which means that the sugars produced can be directly delivered through a pipeline between the two plants, with a significant saving in transportation costs.

5.3.4.3 Funding infrastructure

In the structural analysis, we recurrently identified the lack of funding as a barrier for further corn stover value chain development in Flanders, especially regarding projects aimed at integrating all the information produced by the different researchers, coordinating further

[19] Respondents also noted there are also some relatively small farms cultivating about 40 hectares of land in total.

knowledge development, and bringing together the different stakeholders. At the European level, several funding schemes and initiatives exist in order to support the development of value chains, e.g. the agricultural European Innovation Partnership (EIP-Agri). They support the development of sustainable food and non-food value chains through their multi-actor project, funded by the Horizon 2020 budget. The European Technology and Innovation Platform (ETIP) Bioenergy focuses partly on the use of lignocellulosic crops and agricultural residues for the production of bioethanol and biodiesel, and also the “Competitiveness and Innovation Framework Programme – Entrepreneurship and Innovation Programme (CIP-EIP) supported the development of value chains, financed by the Horizon 2020 budget (Scarlat et al. 2015). Over the years, different attempts have been made by the Flemish stakeholders to acquire either Flemish or European funds for specific tresearch on setting up a corn stover value chain in Flanders. However, they have remained unsuccessful. Regarding the European funding, the reason for rejection are unknown by the authors. According to Rösch and Kaltschmitt (1999), acquiring European funds is challening as there are many different calls, and the conditions for application are not always clear. Furthermore, fierce competition exists for acquiring funds. With regard to Flemish funds, the stakeholders challenge that none of the available funds seemed to be appropriate for the development of a corn stover value chain. Indeed, respondents stressed multiple times that the funds focus mainly on innovation in one link of the value chain, such as the farmers, or SMEs, rather than on the development of whole value chains from field to product.

This focus on the entire chain is exactly what did occur in Ontario. At the start, initial knowledge development projects were conducted by different agencies, funded by different federal and provincial sources. During this phase, several research partners also experienced fierce competition for funding, which caused some discontinuity in the funding and slowed down the project. However, in the end, partners managed to obtain funding. By involving the policy makers in their projects, they were able to justify the funding and to inform the partners of other funding opportunities.

With respect to subsidies, provided once the value chain is established, a large difference in attitude between the two regions is observed. In Flanders, different respondents stressed the need for subsidies to make this kind of value chains economically viable. In Ontario, the value chain development was supported by different funds. However, after its development, the goal is to be largely independent of subsidies, as demonstrated by the first selection criterion for the technology provider, which was “economic viability without subsidies”. When asked about subsidies, one respondent stated: “*That is a bonus, and you take the bonus for the years you get them”* (Boundary spanning actor). This difference in mindset has consequences for the way in which the value chain is developed, and its sustainability, especially given the increasing subsidy uncertainty in both regions.

5.3.4.4 Institutions, interactions and policy coordination

Many, in particular hard, institutions indirectly support corn stover value chain development in Flanders. Firstly, at the level of the European Union (EU), the Renewable Energy Directive[20] was established to promote the use of renewable sources for the production of energy in the EU. In particular, the revised version states that, by 2030, 27% of the energy consumed must be produced from renewable sources, including biomass. Given the food-versus-fuel debate, in which different actors have drawn attention to the risk of converting farmland used for food production to farmland for the production of biofuels, and the associated risk of increased land use change and deforestation, the authorized contribution of foodcrop-based biofuels and bioliquids is limited to 10% for renewable energy used in the transport sector and only 5% of the overall energy consumption by 2020. In this respect, corn stover becomes interesting because the European Commission (EC) recognizes the remaining inputs will need to come from 2nd or 3rd generation resources (European Commission 2012b). Furthermore, the EC and the OECD (Organisation for Economic Cooperation and Development) both published a strategy highlighting the need for a transition from a fossil-based economy towards a bioeconomy (European Commission 2012a; OECD 2009; De Besi & McCormick 2015). Also, the Flemish government is pursuing the transition to a bioeconomy, demonstrated by the establishment of the “Interdepartmental Working Group for the Bioeconomy” and the publication of a strategy entitled “Bioeconomy in Flanders: The vision and strategy of the Government of Flanders for a sustainable and competitive bioeconomy in 2030” (Departement Leefmilieu Natuur en Energie 2013). In these strategies, a systems perspective is highlighted, as well as the need for collaboration and innovation stimulation by involving all actors (Departement Leefmilieu Natuur en Energie 2013; De Besi & McCormick 2015). More recently, the initiative “*Vlaanderen Circulair*” (Circular Flanders) was established, set up as a partnership between policy makers, private partners, civil society organisations, and research institutes to promote the development of a circular economy in Flanders (OVAM 2017). Only the future will tell whether this initiative can help to establish sustainable collaborations for whole value chain development.

Another indirect policy action, also promoted under the Common Agricultural Policy (CAP) of the European Union, concerns the need for collaboration between the different actors in the value chain. In particular for agro-food value chains, this policy framework encourages

[20] COM/2016/0767 final/2 - 2016/0382 (COD)

producers and other value chains actors to organize themselves in producer organisations (POs) or interbranch organisations (IBOs) (Borst 2017). POs have the goal of promoting collaboration between the farmers/producers and to help them get organized in order to be able to jointly supply goods to the market (Regulation No 1305/2013). As such, they focus on adapting the production to market needs (both quantitative and qualitative), on concentrating supply and on marketing the products of their members and on optimizing production costs and streamlining of producer prices (Amat et al. 2016). Many of these POs have been established under the form of cooperatives. These POs form an important mechanism to bring together the farmers, but they only cover the production aspect of the value chain, in order to strengthen their bargaining position vis-à-vis the other stakeholders in the value chain, including processors. The value chain perspective, however, is missing.

Taking this into consideration, and in order to promote a complete value chain approach, the promotion of IBOs in the EU offers an interesting opportunity. Indeed, the goal of IBOs is to "establish a dialogue between various food chain actors with a view to fostering marketing coordination, improving knowledge, exploring marketing potentials and many other tasks" (Amat et al. 2016, p.9). Following EU regulation (Regulation No 1308/2013), IBOs cannot be directly involved in the production, processing or trade of products. However, their goal is to enhance collaboration amongst the stakeholders in the value chains by doing research, investigating how the value chain can be organized, enhancing dialogue between the actors in the value chain and promoting best practices and market transparency. In order to become an IBO, organisations need to be officially recognized as IBO by the Member State (Amat et al. 2016). While in Flanders IBOs can officially be recognized, so far no IBO has been granted recognition. The reason might be that no financial incentives are given to establish an IBO in Flanders and organisations that carry out the same functions, often prefer a simpler structure than the one proposed by EU law.

While currently the focus for IBOs is on food value chains or the use of agricultural crops for the production of ethanol, we question whether it would be interesting to set up a similar structure for the use of cellulosic biomass for the biobased economy? Such an IBO could then serve as (1) a platform for discussion between the actors; (2) focal point for policy dialogue with government and public authorities; (3) collection and distribution of technical and economic knowledge; and (4) improved communication between the stakeholders (Amat et al. 2016). However, in order to realize this, support should then be given by the local authorities, as well as from the EU."

The qualitative research further provided some insights into the soft institutions in Flanders. Firstly, different actors referred to the poor image of biomass processing plants, and appeared to be rather sceptical when talking about the biobased economy. For example, several farmers and custom harvesters questioned the economic viability of anaerobic digestion plants specifically, and biorefineries in general. Hence, they indicated that they would be interested in selling or harvesting the stover in order to increase and diversify their income, but they do not want to make the necessary investments themselves. Similarly, different processing companies showed interest, but refrain from taking further actions themselves.

In Ontario, the development of a corn stover value chain is considered beneficial, as it contributes to agricultural diversification and rural development, which is important given the flattening of the chemical industry in Sarnia. Also, it fits perfectly in Ontario's Climate Change Action Plan (Ministry of the Environment and Climate Change 2017). Nevertheless, corn stover value chain development also experienced some challenges from an institutional perspective. In 2008, the provincial government of Ontario announced a coal phase-out for the production of energy, which hinted at the use of biomass. However, since the technology was not yet in place, policy makers decided to go for natural gas instead. Later on, with the discovery of new deposits, low gas and fuel prices further drew investment dollars away from biomass.

Overall, policy makers take a hands-off-approach regarding the development of the new value chain, letting the private partners decide on the specific arrangements. In this respect, policy interventions and rule setting will only be done if considered necessary. Furthermore, several respondents challenged the lack of one ministry taking the lead, as many different aspects of the bioeconomy are dispersed over a large number of ministries[21]. Some working groups have the function of reducing this dispersion, including the Bioeconomy Interdepartmental Working Group at the federal level, the Federal-Provincial-Territoral Bioproducts Working Group and the Industrial Bioproducts Value Chain Round Table. This last initiative hosts both representatives from industry, including BIC and OFA, as well as provincial and federal policy makers. However, despite these working groups, ministries and policy makers generally still take a sectoral approach, and "value chain thinking" is limited. With the corn stover value chain now being developed, policy makers have realized the value of this "value chain thinking" and have started to appreciate the need for it.

Finally, the different commodity organisations also still doubt whether they should become actively involved in the corn stover value chain development, apart from giving some feedback on the process. Indeed, as their income generation is based on the sale of the grain and not the harvest residues, they wonder whether they are responsible for developing such value

[21] These ministries include the Ministry of Economic Growth and Development, Ministry of Environment and Climate Change, Ministry of Research and Innovation and Ministry of Agriculture, Food and Rural Affairs.

chains. Additionally, they are rather conservative, as they do not want to lead their members towards investment in something that still has chance of failure.

The farmers' attitudes towards corn stover value chain development are somewhat ambiguous. On the one hand, many respondents stressed that one of the most important reasons for farmers to participate in the corn stover value chain is the extra income they can generate without having to invest in additional land or assets, which further diversifies their income. Additionally, many farmers explicitly mentioned the desire to become part of the value chain, rather than just being suppliers. Furthermore, farmers applying no-till, are highly in favour of removing their stover, as there is a general belief that because of higher corn and corn stover yields, soybean yields have declined under the no-till practice. Indeed, under no-till, the large volumes of corn stover lead to poorly drained soils and to lower soil temperatures (2 – 3°C lower), leading to later and poorer emergence of soybean, and as a result, lower soybean yields (Vanhie, Deen, Lauzon, et al. 2015). Taking away part of the stover could keep the farmers on no-till, while still maintaining good soybean yields (Vanhie, Deen, Bohner, et al. 2015). On the other hand, some respondents warned that farmers can be quite risk averse and conservative regarding investments in a new value chain. As such, only the future will tell whether the CSPC can attract sufficient members and investors to participate in the corn stover value chain. Finally, the local population is also in favour of the project. Indeed, as Sarnia suffered from serious water and air pollution problems in the 1970s and 1980s, there is now a kind of openness towards greener technology and investment in the biobased economy.

5.3.4.5 Market structure

At first, for the industrial partners involved in the advisory committee in the Ontario case, it was not easy to share sensitive proprietary information about their techniques or financial aspects. Therefore, in order to convince them to participate and to encourage them to give feedback, non-disclosure agreements were signed between the partners, ensuring that the information shared would not become public. Furthermore, discussions were held on what kind of information the partners were comfortable with sharing, such as industry standard numbers or ranges. Once a certain comfort level was reached among the partners, information sharing between the members of the advisory committee went a lot more smoothly. Different respondents noted that time played an important role, and trust cannot be forced upon the members: "*And I think everything that we did along the way, we had to learn. And if you try and short-circuit that, you will lose the ability to create the trust, the communications, the marketing, the change of mindset that needs to go on. That all takes time and you got to constantly feed it with relevant information.*" (Boundary spanning actor)

5.3.4.6 Directionality and demand articulation

There is a clear difference in directionality between the two cases.

The structural analysis shows a lack of directionality in Flanders. At the moment, it remains unclear what valorisation trajectory would be the most suitable or which technologies can be used. As a result, it is difficult to assemble the right partners or collect information in a structured way to move the project forward. Furthermore, while private partners show interest, they are not willing to take further steps. Therefore, it could be useful to inform all potential stakeholders of the benefits, such as extra income, extra labour opportunities, alternative resources for processes, the avoidance of the food-versus-fuel debate, or the fact that at the moment there is no competition for this resource.

In Ontario, the project started from the desire to produce cellulosic sugars, with the aim of reviving and growing the local chemical industry with a biobased chemical focus. Corn stover as a biomass source was only selected in a subsequent phase of the project. Hence, as the goal of the project was clear from the start, it was easier to direct the research and assemble the necessary partners. However, merely assembling all relevant stakeholders proved insufficient. Indeed, at the start of the project, the different stakeholders had different expectations of the outcomes. For example, the farmers' goal was valorising their stover to increase the income from their land and increasing soybean yields, while the goal of the industrial partners was to see whether the sugars produced could be of any value to them. Furthermore, the different stakeholders also had different perceptions of the challenges relating to the project, which were unknown to other stakeholders. For example, while for farmers one of the key challenges to be addressed was the effect of corn stover harvest on the soil organic carbon (SOC), or the weather conditions during the harvesting period, the industrial stakeholders were more worried about logistics and supply issues. As a result of the boundary spanning initiatives conducted by BIC, as well as leaving time for the partners to get to know and trust each other, a common vision was created. As one respondent stated: "*So that everyone has a better understanding of the challenges, like for example, as a producer, weather is a key challenge and harvesting sustainably, those are key challenges that somebody further along the chain may not have thought about previously.*" (Researcher)

5.3.4.7 Reflexivity

In Flanders, the development of a corn stover value chain is still in the exploration phase. Therefore it is hard to evaluate the reflexivity. In Ontario, on the other hand, several examples prove the reflexive nature of the system. For example, originally, in early studies, the cellulosic sugar production plant was planned to process 250,000 ton DM of corn stover per annum.

However, as more information became available, the advisory committee decided to bring down the scale to 75,000 ton DM, which was perceived to be more realistic. Furthermore, at first, the plant was intended to only run on corn stover. However, after a while, it became clear that it would be difficult to reliably collect 75,000 tons DM of corn stover each year. Therefore, the project partners decided to also include wheat straw in the process. This proved to be a good decision. Indeed, not only will the supply certainty be enhanced, after new calculations it also became clear that logistical costs would be greatly reduced because of the prolonged harvest period. As such, the advisory group, meeting regularly and giving feedback to the studies, proved to be a good platform for interaction and reflection on alternative options.

5.4 **Discussion**

From the results above, we obtained insight into the functional and systemic merits and failures of the two case studies. From this analysis, we are able to distil success factors that have contributed to the development of a corn stover value chain. While these experiences are very interesting, we also need to acknowledge that the value chain developed cannot simply be transferred to Flanders, or other regions. As stated by Asheim and Coenen (2005), the specific characteristics of the region should also be taken into account. As such, the goal of this paper was not to describe the specific details of the value chain being developed. Instead, it is merely the process of achieving this value chain that is interesting and that could be applied in other regions. As one stakeholder stated: "*So again, you have to look at your logistics and your system. But can you take the learnings? You have to. It is ridiculous not to.*" (Representative of farmers' association). Hence, below, we present four success factors from the two case studies, which can be used for local biomass value chain development.

5.4.1 Success factor 1: Determine goal of the value chain

One of the main success factors in the Ontario case study proved to be the clear definition of the project goal from the start, namely the production of cellulosic sugars from corn stover. Indeed, having a clearly defined project goal allows to bring the right stakeholders to be brought together and to make them aware of the opportunities of the value chain. Indeed, the importance of having a clearly defined goal has been mentioned in literature related to project management or (open) innovation management (e.g. Goduscheit and Knudsen, 2015; Melese et al., 2009; Van Lancker, 2017). Additionally, transition theory also stresses the importance of a shared vision and common goal as a paramount factor in transition efforts (Budde et al., 2012; Farla et al., 2010; Lopolito et al., 2011; Smith et al., 2010).

From the case study in Flanders, we see that, as the system is still in an exploratory phase, the lack of a goal-oriented vision hampers engagement by private actors as there is a feeling that the value chain can still go in any direction. The lack of directionality also resonates in the technology overview. In Ontario, it seems that all the technological decisions have been made, whilst retaining some room for reflection and adjustments. In Flanders, many questions remain about how the corn stover value chain will be organised from a technical perspective, including the harvest and storage methods, caused by uncertainty about which valorisation trajectory to pursue. Hence, we learn that clearly articulating the value chain goal enhances value chain development, and is a first step in creating a common vision amongst the different stakeholders.

5.4.2 Success factor 2: Consider whole value chain and actively involve all stakeholders from the start

From the analysis, we learn that one of the greatest success factors for the value chain development process in Ontario was that all actions were being conducted with the value chain perspective in mind. First, for a corn stover value chain to be developed, the reliable supply of corn stover is crucial. Part of the success of the Ontario case study is that they did not take corn stover supply for granted, but actively involved producers from the start. As one respondent stated: "*It is easier if you have the agricultural producers early on in the game so they understand what this opportunity might look like.*" (Policy maker). As producers were directly involved, their concerns could be taken into account in the establishment of the value chain. Furthermore, benefits for them to participate were clearly articulated. These two aspects increased the chance of farmers participating. Secondly, a reliable technology provider needed to be involved. As the Ontario case study shows, while finding the right technology provider required time and effort, this paid off in the end. Thirdly, off-take of the products needed to be guaranteed. Therefore, the researchers at BIC purposely aimed to produce sugars, as these were found to be the basis for the chemical industry which was already available in Sarnia. Hence, part of the success can be attributed to the fact that the value chain did not aim to create a whole new market for its end-products but rather aimed to feed into an already existing market. This success factor was also recognized by Rösch and Kaltschmitt (1999) who stated that in order to reduce the risk of failure for bioenergy products, off-set needs to be assured. This can be done by signing off-take agreements and by capitalizing on a sufficiently large market (Rösch & Kaltschmitt 1999).

Involving all these stakeholders from the start was also found to be crucial. This was also confirmed by Schmid et al. (2012) who argued that farmers and SMEs can contribute greatly to innovation processes, by sharing local knowledge. Furthermore, they acknowledged the need for cooperation between producers and the other actors in the value chain to enhance the development of the biobased economy, for example by setting up multi-stakeholder partnerships involving civil society groups, farmers, scientists, representatives of bio-based industries and consumers (Schmid et al. 2012). In the Ontario case study, such a multi-stakeholder platform was created in the form of the advisory committee, in which the different stakeholders were represented. Furthermore, the role of BIC as a boundary spanning actor proved to be crucial. Indeed, the crucial role of boundary spanning actors has already been widely acknowledged in the literature (Williams 2002; Klerkx & Leeuwis 2008; Tribbia & Moser 2008; Elzen et al. 2012; Kivimaa 2014; Smink et al. 2015; Howells 2006; Smedlund 2006). In Flanders, plans to establish a similar steering committee were made, but were never executed because of a lack of funding.

5.4.3 Success factor 3: Create trust and enthusiasm amongst all stakeholders in the value chain

Analysing the development of the corn stover value chain in Ontario, we found that another major contribution to its success was the creation of trust and enthusiasm for the new value chain amongst all the stakeholders involved. The importance of trust creation in developing innovative value chains was also recognized by (Van Lancker 2017; Rösch & Kaltschmitt 1999).

In the corn stover project, farmers' trust in the value chain was enhanced through several initiatives: harvest demonstrations at large farm shows, online videos, etc. Indeed, Klerkx et al. (2010) stated that these kind of "tangible visions help create shared understanding and support of actors" (Klerkx et al. 2010, p.399). Secondly, different respondents stressed the importance of working with so-called champions, as was also acknowledged by (Kivimaa 2014). Their role is to generate trust in the project amongst the other farmers and to trigger them to participate. One respondent described it as follows: "*I think too it is important to have, I will use the term, to have some champions of the project, who really generate interest and talk about it and keep driving the project forward.*" (Researcher).

Furthermore, trust needs to be generated in the quality of the sugars produced, in order to convince customers to sign off-take agreements. After organizing some blind-testing of sugars produced by several technology providers, the potential off-takers gained trust that Comet Biorefining was a suitable processor which could reliably provide the sugars they needed.

Additionally, trust between the different members of the advisory committee also proved to be important. In particular, the signing of the NDAs proved to be a catalyst for trust, before this could develop further over time. One issue was indentified with the potential to endanger the trust developed, namely discussions on the corn stover price. As expected, farmers wanted the highest price possible, while the industrial partners wanted the lowest price possible. In order to avoid the chance of creating frictions between the committee members, the price discussion was avoided as far as possible and postponed towards the end of the project.

Finally, trust needs to be created with policy makers. This was realized by having policy makers sit on the advisory committee. Instinctively, this may seem risky, as besides the positive results, uncertainties and potential negative effects of the corn stover harvest project were also discussed. This could lead to policy makers doubting the whole project, depriving them of subsidies, and potentially hampering further progress. However, the opposite happened. Indeed, by being honest about all the uncertainties and demonstrating how these uncertainties could be addressed, policy makers had even greater confidence in the project and its benefits. One policy maker articulated this as follows: "*And it was very like I said very open. I did not feel they were holding back because I was from the government. And I thought sometimes they forgot I was there you know. So that was positive for me. It was, you know to, then you feel more comfortable you know, not seeing all the polished version. You get to hear it in difficult moments.*" (Policy maker). Hence, from this experience, we learn that actively involving policy makers in the process and being fully transparent towards them increases policy makers' trust.

5.4.4 Success factor 4: Funding at the right point in time

Although not directly controlled by the stakeholders in the value chain, funding was shown to be an important success factor in the Ontario case study. Certainly, actors can make applications, although actually acquiring the funding is another matter, as competition for funding is often fierce. However, in the end, sufficient funding was obtained. In contrast, as yet, Flemish stakeholders have remained unsuccessful in acquiring the necessary funding, leading to an impasse in the development of a corn stover value chain. Indeed, while in Ontario this funding has been obtained, in Flanders, knowledge development has not yet reached the level at which private partners can be asked for significant in-kind contributions. Extra funding to gather the knowledge acquired over the years and to coordinate the further development of the corn stover value chain therefore seems indispensable.The experience in Ontario indicates that, once the exploration phase is over, funding is more easily acquired, including in-kind contributions from private actors or private banks. This was also acknowledged by Rösch and Kaltschmitt (1999). Therefore, in Flanders, researchers should not be discouraged by earlier unsuccessful attempts to obtain funding, but they should persist and take heart from the experiences in Ontario.

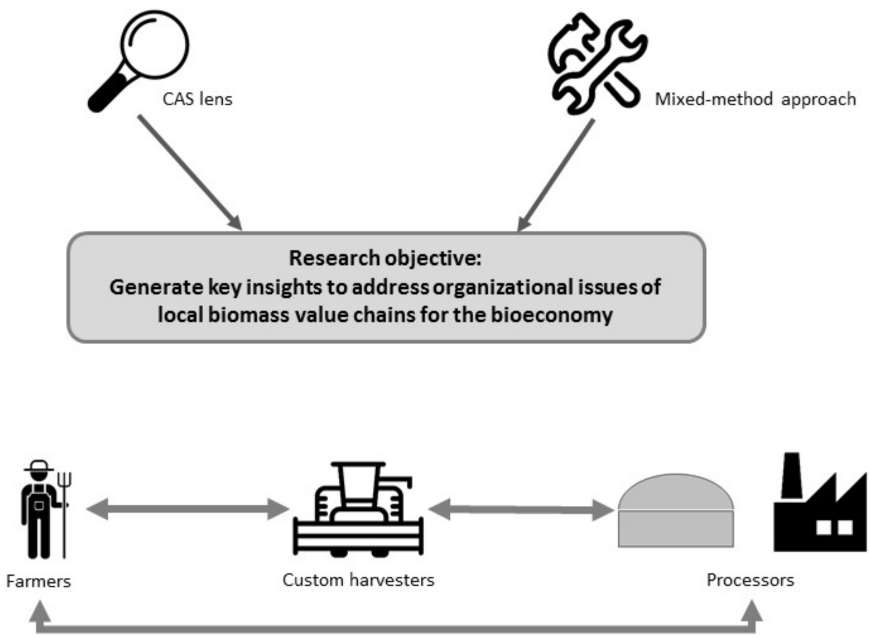
On the other hand, one could state that the Flemish government made the correct decision not to fund extra research in developing a corn stover value chain as they might consider such a value chain unlikely to become successful anyway. However, as experienced during the workshop, we noticed that for some of the stakeholders it was the first time they met each other and shared knowledge. As such, we believe extra funding to assemble the knowledge acquired over the years and to coordinate the further development of the corn stover value chain is needed.

The importance of subsidies remains somewhat unclear. In Flanders, stakeholders argued that a corn stover value chain cannot be economically viable without subsidies. In Ontario, stakeholders deliberately developed their business cases without having to rely on subsidies. While difficult to achieve, avoiding reliance on subsidies to keep the value chain economically viable, seems to be the most sustainable vision in the long-term, given the increasing policy uncertainty.

5.5 Conclusion

The transformation from our fuel-based economy into a biobased economy will not only require the expansion of existing biomass value chains, but also new biomass feedstock will need to be sourced. Successfully developing value chains for these new, usually local, biomass sources, requires tackling both the technological as well as the organisational challenges simultaneously by applying a value chain approach. In this paper, we distil success factors and lessons learnt from two in-depth case study analyses: a successful case study, being the development of a corn stover value chain in Ontario, and a case study where a corn stover value chain is still being developed, namely Flanders. The integrated analytical framework developed by Lamprinopoulou et al. (2014), proved to be well suited to analyse the case studies from an organisational viewpoint. Additionally, thematic analysis was used to investigate the technological issues relating to corn stover value chain development. Four success factors could be deduced: (1) determine the goal of the value chain; (2) consider the whole value chain and actively involve all stakeholders; (3) create trust and enthusiasm amongst all stakeholders; and (4) funding at the right point in time. While these factors are generic, we also stress the need to take into account the regional setting in which the value chain is being developed. Overall, this paper stresses the need for value chain thinking, and presents a process that can be followed when developing innovative local biomass value chains for the biobased economy.

Chapter 6: Discussion and conclusions



6.1 Introduction

The goal of this dissertation is **to generate key insights to address organisational challenges of local biomass value chains in the context of the biobased economy**. Figure 6.1 summarizes how the previous chapters contribute to achieving this objective.

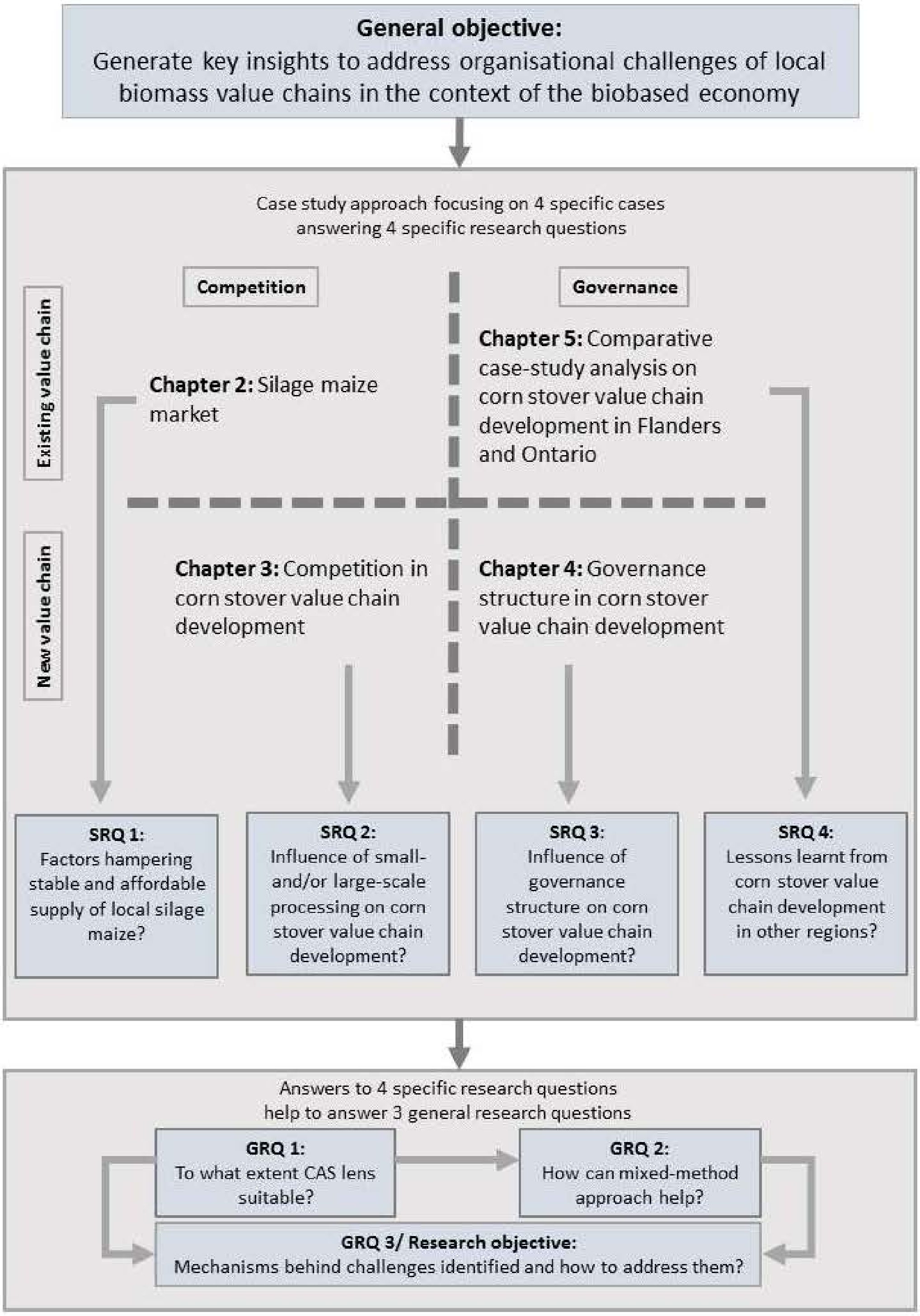


Figure 6.1 Overview of the dissertation structure

Chapter 1 outlines our proposed research. Using a mixed-method approach, including semi-structured interviews and agent-based modelling, four specific case studies relating to local maize value chains were investigated. As shown in Figure 6.1, these case studies can be classified according to the focus on competition for local biomass or the focus on governance without competition, and whether the case study deals with an existing or developing local biomass value chain. The line used in Figure 6.1 to divide the case studies into quadrants is dotted, meaning that the classification boundaries are not absolute. Instead, overlaps exist. Indeed, for example, while chapter 2 focuses on the competition for local silage maize between farmers and a biogas plant manager, it was also important to take into account the governance of the transactions between the different agents. From each case study, we used the insights to provide an answer to a specific research questions. The separate case studies are considered in chapters 2, 3, 4 and 5, where an answer is provided for specific research questions 1, 2, 3 and 4, respectively. These are briefly repeated below.

More importantly, the insights obtained with these four specific research questions, guide the formulation of answers to the three general research questions, which are considered in this discussion chapter. We focus on the suitability of a complex adaptive systems lens (general research question 1) and the use of a mixed method approach to study organisational aspects of local biomass value chains in the context of the biobased economy (general research question 2). Moreover, we present the organisational challenges associated with such value chains and provide recommendations to practitioners and policy makers (general research question 3). This discussion also highlights the contribution of this dissertation to the scientific literature together with its limitations. The final section of this chapter presents the main conclusions of this research and prospects for further research.

6.2 Specific research questions

In chapter 2, we focused on an already existing value chain, being the silage maize market, which is characterized by distinct institutional arrangements. We assessed the contribution of these institutional arrangements to the difficulties experienced by biogas plant managers in obtaining a stable and affordable supply of local silage maize. The qualitative research showed that the use of different units of transaction and different safeguard measures, and the late entry into the already existing silage trade market might have an influence on the development of a supply chain. Comparing different scenarios with an agent-based model, we found that the use of different safeguard measures, i.e. long-term relationships based on trust versus short term contractual arrangements did not have a major effect on silage maize prices; either for the biogas plant managers, nor the farmers. On the other hand, the late entry of the biogas plant manager into the already existing silage maize market increased the price volatility, both for the farmers and the biogas plant managers. In the case of a silage maize deficit, the sudden entrance of the biogas plant manager also increased the silage maize prices paid by the farmers.

In chapters 3 and 4, we investigated the potential of a corn stover value chain, either for large-scale centralized processing, or for small-scale, decentralized processing, or when these two compete. With the help of an agent-based model, we were able to take into account the regional characteristics of Flanders, and using the consumat approach, we were able to model the cropping plant and investment decisions of the farmers and custom harvesters, respectively. We found that under a spot market governance structure, in which farmers interested in selling stover negotiate individually with the processor about the transaction, a corn stover value chain is barely developed when only biogas plant managers are active on the market. A large-scale centralized processor is needed to enhance the development of a corn stover value chain. In the case of competition between a large-scale centralized processor and multiple small-scale decentralized processors, our model results indicated that these small-scale decentralized processors can more readily take up a competitive position thanks to the lower transportation costs. Furthermore, given the highly fluctuating participation rate of the farmers, we concluded that under a spot market governance structure, the potential for a corn stover value chain in Flanders is limited. Indeed, under this governance structure, investments are likely to be too risky. We found similar results under a request-for-purchase scenario, in which the custom harvesters act as intermediaries between the farmers and the processor. Alternatively, we found that a more stable and reliable corn stover supply can be established when a cooperative governance structure is used. However, corn stover supply remains limited. Therefore, in a region with similar characteristics to Flanders, such as small fields and relatively small-scale farmers, we believe a corn stover value chain needs to be directed towards the creation of high value products, which can be produced in intermediate-scale processes. Alternatively, processors could also increase their feedstock flexibility.

Finally, in chapter 5, we presented the results of an in-depth case study analysis, comparing the development of a corn stover value chain in Flanders and Ontario. We were able to deduce four major success factors that contributed to the development of a corn stover value chain in Ontario, and may have hindered the development of a corn stover value chain in Flanders: (1) determine a common goal among all stakeholders, (2) consider the whole value chain and actively involve all stakeholders from the start, (3) create trust and enthusiasm amongst all stakeholders in the value chain, and (4) funding at the right points in time. These will be discussed in more detail in section 6.4, where we formulate recommendations for practitioners and policy makers as an answer to general research question 3.

In the next section, we first extrapolate the findings and conclusions of chapters 2, 3, 4, and 5 to answer the general research questions 1 and 2. We focus on the complex adaptive systems lens and mixed-method research approach, involving semi-structured interviews and agent-based modelling.

6.3 Studying local biomass value chains as complex adaptive systems

In studying the organisational challenges of local biomass value chains in the context of the biobased economy, we approached them with a complex adaptive systems (CAS) lens. After evaluating the four specific case studies, we are able to investigate whether local biomass value chains exhibit the properties and mechanisms of a CAS, by providing an answer to the following research question:

Research question 1: To what extent is a complex adaptive system lens suitable to study local biomass value chains for the biobased economy, taking into account their specific characteristics and those of its actors?

In the introduction and over the course of this dissertation, we described the unique characteristics of local biomass value chains within the context of the biobased economy: the seasonal availability; the low bulk density leading to high transportation costs; the many producers spread over a large geographical area; and the need to establish new relationships. These last two aspects in particular, and the large number of different actors who need to work together, made Rösch and Kaltschmitt (1999) conclude that biomass value chains for applications within the biobased economy exhibit greater complexity than value chains based on fossil resources (Rösch & Kaltschmitt 1999).

However, exhibiting greater complexity does not make these value chains complex adaptive systems. Therefore, we assess whether local biomass value chains for the biobased economy are indeed characterized by the four properties (aggregation, nonlinearity, flows and diversity) that are shared by all CAS and can be described by the three common mechanisms (tagging, internal models and building blocks), as suggested by Holland (1998) and introduced in chapter 1.

According to Holland (1998), the first property shared by all CAS is aggregation. As mentioned in the introduction, aggregation can be interpreted in two ways. On the one hand, it is a way to group the agents, whereby certain characteristics are highlighted and others are ignored. Using semi-structured interviews, we could deduce the following agent groups: farmers or biomass producers, custom harvesters, processors, intermediaries, boundary spanning actors and policy makers. Using tagging, the first mechanism, these groups could sometimes be further split during the research according to certain characteristics. For example, in chapter

2, we split the farmers group into farmers with a silage maize surplus and farmers with a silage maize deficit. In chapters 3 and 4, we split the farmers and custom harvesters into those interested in participating in the corn stover value chain and those who were not.

On the other hand, aggregation also refers to the “emergence of complex large-scale behaviours” (Holland 1998, p.11), which are formed by the confluence of simple behaviours by the actors. As such, the individual decisions of the individual actors lead to a value chain or market with certain characteristics. For example, each individual farmer decides whether or not to remain loyal to long-term relationships when selling or buying silage maize (chapter 2), or he decides which crops to grow and whether or not to participate in the innovative corn stover value chain (chapters 3 and 4); each individual custom harvester decides whether or not to invest in corn stover harvesting equipment (chapters 3 and 4); and each individual processors minimizes his feedstock costs, but at the same time, aims to keep his plant running 24/7, year-round (chapters 2, 3 and 4). Finally, constrained by a limited budget, policy makers need to decide which projects they want to fund (chapter 5). In chapters 2, 3, 4 and 5, we were able to demonstrate how the confluence of the decisions of these individual economic agents in the local biomass value chains, indeed, lead to the emergence of a complex and dynamic value chain, such as a silage maize market or a corn stover value chain. For example, in chapter 3, we demonstrated how the outcomes of the different agents’ decisions are interlinked with each other in a feedback loop. Indeed, we showed how the farmers’ decision to participate in the corn stover value chain is influenced by the prices of the other commodities in the market, but also by the decision of the biogas plant managers to participate and the corn stover prices offered by both the biogas plant managers and the CSPP manager. Next, farmers’ participation rate determines the corn stover supply on the market, and thus whether there is a shortage or abundance of corn stover. Consecutively, this influences how much the processors are willing to pay for the corn stover, again influencing farmers’ participation rate. Hence, this feedback loop demonstrates how the agents’ individual decisions influences the decisions of other agents, resulting in a highly complex and dynamic system.

The second characteristic common to all CAS is <u>non-linearity</u>, implying that the dynamics of the value chain or market cannot be described using linear equations. As such, the confluence of the agents’ interactions leads to complexities that cannot be described by simply summing or averaging the individual actions of the agents. In the previous chapters, we found multiple examples of this complexity, and non-linear behaviour of value chains for locally produced biomass for the biobased economy. In the silage maize market, for example, biogas plant managers face higher silage maize prices, and experience a higher price volatility than the farmers, which cannot be simply explained by calculating the equilibrium price given the local supply and demand. Instead, we found that the local context and the confluence of the farmers’ decisions and interactions lead to a complex and dynamic price formation process. Also in chapters 3 and 4, we also saw some clear examples of non-linear behaviour. The greatly fluctuating participation rate of the farmers, for instance, results from a change in their cropping plan following price fluctuations in markets for commodities other than corn stover. Additionally, participation in the corn stover value chain by one influencing agent might also trigger other agents to participate, leading to a sudden jump in the participation rate.

Thirdly, in each CAS there are flows of goods and information. In our case, these flows of goods were the trade of silage maize and corn stover. However, there is also a trade of information. For example, in chapter 2, we argued that farmers, as opposed to the newly entered biogas plant manager, mutually discuss the silage maize prices, which enables them to better assess current silage maize prices. Flows of information usually run through networks. Indeed, in chapter 2, we highlighted the importance of long-term relationships between farmers in the silage maize market. In chapters 3 and 4, we stated that farmers know the cropping plans and the economic performance of other farmers in their close and broad network. Over time, these networks can evolve, when certain links are broken or new ones are formed. For example, in chapter 2, we found that long-term relationships can be broken when farmers decide to sell their silage maize surplus to a biogas plant manager.

Fourthly, while actors in a CAS can be aggregated as, for example, farmers, or processors (first property), they are also characterized by their heterogeneity, or diversity (final property). For example, farmers differ in the amount of land they have, the crops they grow or their location. Furthermore, some farmers attach greater value to maintaining their long-term relationships, while other farmers behave more opportunistically when they get a better offer, as discussed in chapter 2. This heterogeneity causes different agents to make different decisions when confronted with the same choices, as defined by their internal model, the second mechanism described by (Holland 1998). In chapter 2, the farmers' internal model was mainly determined by the trust function (Equation 2.1 in chapter 2). In chapters 3 and 4, we introduced the consumat approach in order to include the agents' internal model into the agent-based model. To construct the internal models, we used building blocks or "subroutines" (Holland 2006), consisting of simple calculations or if/then rules, which are repeatedly applied by the different economic agents. Different combinations of these building blocks can be used to handle new situations, instead of defining individual behavioural rules for each possible event (Holland 2006). For example, in chapter 2, one of these building blocks was, "sell silage maize to agent with highest score", calculated as a cobb-douglas function balancing the wish to stay loyal and the wish to sell/buy silage maize at the highest/lowest price. In chapters 3 and 4, a building block was, for example, the calculation of the potential gross margin and the actual gross margin. Depending on the ratio between this actual and potential gross margin and the individually attributed aspiration level and uncertainty tolerance, the farmers and custom harvesters in the model followed repetition, deliberation, imitation and social comparison behaviour, which are again examples of building blocks used.

Hence, over the course of this dissertation, we found that value chains for locally produced maize for the bioebased economy indeed contain these four properties of CAS and can be described using the three mechanisms introduced by Holland (1998).

We are now able to evaluate the definitions of CAS to describe local biomass value chains in the context of the biobased economy. As stated in the introduction of this dissertation, Holland (2006) provides a rather general definition, describing CAS as “systems that have a large number of components, often called agents, that interact and adapt or learn” (Holland 2006, p.1). We indeed found that local biomass value chains have a large number of components; a large number of farmers, custom harvesters and processors. In local biomass value chains, these agents interact with each other through the sale and purchase of the biomass, or by spreading of information on prices or economic performance. Furthermore, these agents adapt and learn. For example, chapter 2, we found that farmers that are in long-term trust relationships for the sale of silage maize adapt, and might end this relationship when a biogas plant managers enters the market. In chapters 3 and 4, we described how farmers adapt their cropping plan as a result of fluctuations in commodity prices.

The definition by Holland (2006) does not explicitly mention agents purposely directing the system to a certain goal and it does not seek to clarify the drivers behind the interactions and adapting or learning behaviour. However, as we aimed to gain insights into the mechanisms that drive organisational challenges of local biomass value chains, a more specific definition might be more appropriate. In this regard, the definitions provided by Tesfatsion and Judd (2006) are interesting, as they explicitly include these drivers, with increasingly sophisticated behaviour due to adaptation and learning of the agents. We repeat the definitions by Tesfatsion and Judd (2006) here:

(1) “A complex adaptive system is a complex system that includes reactive units, i.e., units capable of exhibiting systematically different attributes in reaction to changed environmental conditions.”

(2) “A complex adaptive system is a complex system that includes goal-directed units, i.e., units that are reactive and that direct at least some of their reactions towards the achievement of built-in (or evolved) goals.”

(3) “A complex adaptive system is a complex system that includes planner units, i.e., units that are goal-directed and that attempt to exert some degree of control over their environment to facilitate achievement of these goals” (Tesfatsion & Judd 2006).

Definition (3) comes closest to describing the local biomass value chains. Indeed, in this dissertation, the reactive units of the CAS were farmers, custom harvesters, processors, policy makers, etc. Our qualitative research showed that each agent involved in the value chain tries to achieve his own goals. For example, in the silage maize market study, we found that the goal of the farmers is to sell their surplus silage maize at the highest price possible, or to buy the silage maize for the lowest price. However, this goal is attenuated by the goal of remaining loyal to long-term informal relationships. Moreover, in chapters 3 and 4, we saw that farmers and custom harvesters try to facilitate the achievement of their goal, namely to increase their actual gross margin, by looking within their environment and copying the behaviour of the best performing agents.

However, what seems to be missing in all four definitions provided is the explicit reference to the four properties and three mechanisms common to all CAS, which we consider important to describe CAS systems. Therefore, we propose following description of local biomass value chains in the context of the biobased as complex adaptive system:

A local biomass value chain in the context of the biobased economy can be considered as a complex adaptive system, in the sense that:

- it consists of a larger number of heterogeneous economic agents, which can be aggregated according to their function in the value chain: farmers, custom harvesters, processors, but also policy makers, researchers, boundary spanning agents, etc.,
- agents interact with each other generating flows of goods and information
- agents adapt to and learn from their environment and the other agents in the system,
- it gives rise to the emergent phenomenon, i.e. the value chain with distinct characteristics, such as the possibility of non-linear trends.

Overall, we can conclude that CAS theory, including the four CAS properties and three CAS mechanisms, as well as the definition (3) provided by Tesfatsion and Judd (2006), provides a suitable lens and starting point to investigate the organisational challenges of local biomass value chains in the context of the biobased economy.

Research question 2: Given the CAS lens, how can the use of a mixed method approach, comprising semi-structured interviews and agent-based modelling, help in examining the mechanisms that drive the organisational challenges associated with local biomass value chains in the context of a biobased economy?

Acknowledging that local biomass value chains in the context of the biobased economy are complex adaptive systems, we now have to evaluate whether the mixed-method approach, combining semi-structured interviews and agent-based modelling, contributed to explore and gain insight into the organisational challenges of such value chains. In doing so, we first motivate our decision to use agent-based modelling and detail the benefits and challenges associated with this method. Secondly, we focus on the interplay between and the added value to the joint use of semi-structured interviews and agent-based modelling to study CAS in general, and local biomass value chains specifically.

6.3.1 Agent-based modelling: a method designed to study complex adaptive systems

Having “direct historical roots” in complex adaptive system theory (Macal & North 2009, p.89), it is widely acknowledged that agent-based models are particularly suitable for studying complex adaptive systems (North & Macal 2007; Borrill & Tesfatsion 2010). As explained multiple times throughout this dissertation, the goal of ABMs is to help researchers to understand the mechanisms operating at the micro-level that lead to the specific features of the complexity observed at the macro-level. As such, in agent-based modelling, the researcher models the micro-level behaviour and interactions of the different agents involved in the complex adaptive system, and observes how this influences the observed complex adaptive system at the macro-level. More specifically, in our case, the agent-based models help us to understand the mechanisms at the micro-level that drive the organisational challenges of local biomass value chains observed at the macro-level, by simulating the individual behaviour of and interactions between the farmers, the custom harvesters and the processors. For example, in chapter 3, we demonstrated how individual farmers’ decisions, influenced by the prices of corn stover and other commodities, led to a largely fluctuating corn stover supply.

As described in the literature and as we experienced during our research, using agent-based models as a research tool has some advantages, which makes them more suitable to study organisational challenges of CAS compared to other modelling techniques. The first advantage of agent-based modelling is that, unlike other, more conventional mathematical programming approaches, such as top-down optimization models, ABMs take a bottom-up approach, in which agents continuously adapt and evolve as a result of interactions with each other and their environment (Barnes & Chu 2010), following simple behavioural rules. As such, these models allow to take into account the dynamical and adaptive characteristics of the complex system’s elements, which is not the case with for example general or partial equilibrium models. The micro-level actions and interactions lead to macro-level effects, which can then be observed and analysed by the researcher (Borrill & Tesfatsion 2010). As such, ABMs can be used as computational laboratories, in order to observe and understand what happens at the macro-level when initial micro-level conditions are changed (Tesfatsion & Judd 2006). Additionally, and in contrast to more conventional modelling approaches that assume rationality, agent-based modelling allows the researcher to take into account the bounded rationality of the agents. This implies that the agents cannot know everything, nor are they able to calculate everything. For example, in chapters 3 and 4, the agents can only assess the behaviour and performance of other agents within their close or broad network, and not of agents outside their network. Finally, ABMs can be used when systems are computationally irreducible, meaning that the behaviour of the system cannot be directly translated into mathematical equations, but can better be described by, for example, if/then-rules.

However, agent-based models also have some drawbacks. Most of these drawbacks relate to the balance between, on the one hand, increasing model detail to be able to grasp the full complexity of the system and, on the other hand, ensuring a thorough understanding of the model itself, which is also known as the balance between descriptive accuracy and analytical tractability (Windrum et al. 2007). Increasing model detail can help in approximating reality, as often agent-based models are found to be too abstract or too far from reality and oversimplifying social processes (Waldherr & Wijermans 2013). However, as model complexity increases several difficulties arise. Firstly, because of the way of modelling, even simple agent-based models consists of many coding lines. Increasing model complexity and hence, increasing the complexity of the model code also increases the possibility of errors in de modelling code. As Gilbert (2008) stated: “you should assume that, no matter how carefully you have designed and built your simulation, it will contain bugs” (Gilbert 2008, p.38). Errors in coding are difficult to detect, because the modeller does not know beforehand if the complex adaptive system of study will arise from his simulations and how the characteristics are influenced, as this is the scope of the study. Hence, it is challenging to ascertain that the model results do not orgiginate from errors or artefacts in the model code (Galán et al. 2009). Furthermore, ABMs generally have many parameters for which input data cannot always be found. Consequently, often assumptions need to be made (Yang & Gilbert 2008; Boero & Squazzoni 2005). Moreover, agent-based models sometimes come across as black box (Waldherr & Wijermans 2013), complicating the interpretation fo the model results. Finally, often researchers from other disciplines wonder whether such complex models are actually needed, and if no simpler models could produce the same results (Waldherr & Wijermans 2013).

Given these difficulties, in our research we deliberately tried to make some simplifications when developing our agent-based models. Indeed, instead of trying to model every detail, we tried to find a proper balance between the descriptive accuracy and the analytical tractability. According to Holland (1998) it is indeed up to the modeller to select which features are important to answer the research question, and which can be ignored. Despite the simplification, our models still contained many parameters for which input data needed to be provided, as is common in agent-based modelling (Windrum et al. 2007).

Many of these parameter values were retrieved from empirical data (e.g. farmers' surveys (FOD Economie-Algemene Directie Statistiek 2014)) and from the literature (e.g. (FOD Economie-Algemene Directie Statistiek 2017; Wageningen UR Livestock Research 2014; Wageningen UR 2014)). However, acquiring empirical data for all model components proved to be difficult, and sometimes assumptions needed to be made. Boero and Squazzoni (2005) mention that, even in the best case scenario, only some model components can be fed with empirical data, while others cannot. For example, in chapter 2, we assumed a triangular distribution for certain parameter values, including the trust factor and base level trust. In chapters 3 and 4, we made assumptions on the uncertainty values and aspiration levels, based on the data provided by van Duinen *et al.* (2016). Sensitivity analysis is a way to ascertain that the model parameters, which could not be fed with empirical data, do not have a significant effect on the model results. However, one should also acknowledge that it is almost impossible conduct a sensitivity analysis for all model parameters (Yang & Gilbert 2008). In this respect, in chapter 2, we tested if the model results hold in three different market situations. A more thorough sensitivity analysis was conducted for the model of chapter 4, which is presented in Annex C. Additionally, in order to reduce the probability for coding errors and bugs in the model, we developed the agent-based models discussed in chapters 3 and 4 in close collaboration with an experienced agent-based modeller.

Moreover, the discerning reader might have noticed a particularity when comparing the results presented in chapters 3 and 4 on the market characteristics in case of only a cellulosic sugar production plant active in a corn stover spot market. While these results are based on the same model and simulating the same scenario, they are indeed slightly different. These differences can be explained by the use of different model input parameters (annexes B and C), such as the collection efficiency (0.8 in chapter 3; 0.6 in chapter 4). Furthermore, in chapter 4, we allowed the simulated custom harvesters to take into account the possibility that the stover cannot be harvested because of wet weather conditions, with a probability of occurrence of 20%. These choices explain the higher corn stover supply in chapter 3 than in chapter 4. However, despite these differences, we observe that our main findings remain the same: under a corn stover direct sale governance structure we find that farmers' participation rate and corn stover supply are largely fluctuating, making investments very risky. Hence, the comparison of the results of chapters 3 and 4 for the direct sale market in which only the CSPP is present on the market can be considered as a kind of sensitivity analysis, revealing that our findings remain valid even though other input data were used.

Furthermore, similar to Knoeri *et al.* (2011) and Valente (2005), we found that operational validation of our ABM results was challenging. Operational validation is defined as "determining that the model's output behavior has sufficient accuracy for the model's intended purpose over the domain of the model's intended applicability" (Sargent 2004, p.3). In order to validate our results, we organized the workhop "*Maïsstro, waardevoller dan u denkt"* (Corn stover, more valuable than you think) in December 2015. During the workshop we introduced the model assumptions, behavioural rules and parameter values used in the ABM for the research on corn stover value chain development to 11 experts. Furthermore, we presented them the initial model results. Thanks to their feedback, we were able to improve our ABM. This kind of validation is known as "conceptual model validation" (Sargent 2004; Knoeri et al. 2011), which is defined as "determining that the theories and assumptions underlying the conceptual model are correct and that the model representation of the problem entity is reasonable for the intended purpose of the model" (Sargent 2004, p.3). Knoeri *et al.* (2011) believe that conceptual model validation is even more important than operational validation in enhancing the model validity. Furthermore, we found that in presenting the model details and results to the experts at the workshop, the model served as a kind of communication tool, bringing the different stakeholders together, allowing them to gain insights and triggering them to discuss the results and its implications amongst each other. However, more of such workshops should be organized in order to be able to confirm and gain more insights into these processes.

The decisions to keep the models in our research relatively simple to use conceptual model validation, implies that our objective was not yielding numeric results, but understanding the different mechanisms that influence the organisational challenges of local maize value chains. This way of conducting and interpreting ABM results is also supported by other authors, including (Holland 2006; Valente 2005; Moss 2008). In other words, agent-based modelling, in the way we applied it, is primarily a quantitative method to gain qualitative insights. This was also recognized by Bonabeau (2002), who state that the quantitative outcome of the model simulations should guide a qualitative interpretation, especially when assumptions need to be made on the input data.

6.3.2 Interplay between semi-structured interviews and agent-based modelling

Figure 6.2 shows how jointly using semi-structured interviews and agent-based modelling contributes to the understanding of CAS. In the following sections, first we discuss how the qualitative research contributed to the development of the ABMs. Next, we discuss how the insights obtained from the ABMs gave an extra dimension to our understanding of the qualitative results of the semi-structured interviews. Thirdly, we discuss, based on our model results, how additional qualitative research helped us to further interpret and contextualize the results of our ABMs.

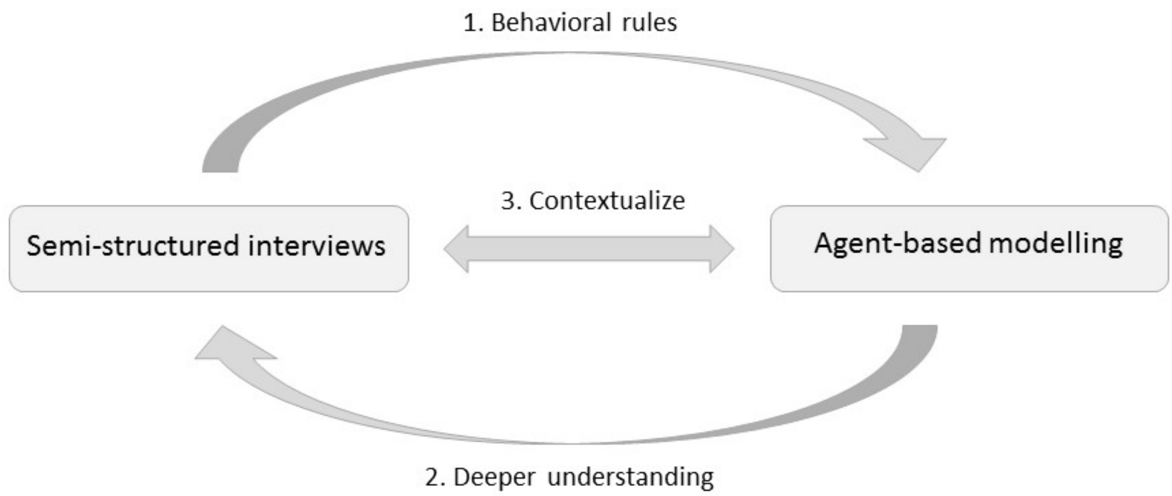


Figure 6.2 Schematic presentation of the interplay and added value of using a mixed-method approach, including semi-structured interviews and agent-based modelling

1. Contribution of the semi-structured interviews to the ABMs

In order to construct the agent-based models, we needed a thorough understanding of local maize value chains. Therefore, we conducted and analysed 56 interviews with stakeholders in Flanders and Ontario over the course of the research period (Table 6.1).

Table 6.1 Overview of interviews conducted. The symbol '#' stands for 'number of'.

Region	Function	# respondents
Flanders	Farmer	10
	Custom harvester	3
	Harvesting equipment retailer	1
	Representative from industry	9
	Intermediary	2
	Policy maker	1
	Representative farm organisation	3
	Researcher	5
	Total number of respondents	*34*
Ontario	Farmer	5
	Harvesting equipment retailer	1
	Representative from industry	3
	Boundary spanning actors	3
	Policy maker	2
	Representative from farm organisation	4
	Researcher	4
	Total number of respondents	*22*

We used the narrative data from these semi-structured interviews to construct the agent-based models, after they were fully transcribed and analysed using NVIVO11. The process followed to go from semi-structured interviews to develop agent-based models is described in Annex D. This way of using qualitative data from semi-structured interviews was also suggested by Boero and Squazzoni (2005) and has been applied by multiple researchers (e.g. (Taylor 2003; Bharwani 2004; Yang & Gilbert 2008; Geller & Moss 2008; Edmonds 2015). Hence, in the first place, we analysed the interviews with a focus on identifying the main economic agents influencing the value chain, their behavioural rules, the flows of goods and information between these agents, and the most influencing aspects in which these agents differ from each other (heterogeneity). For example, in the research on the silage maize market, the insights from the interviews allowed us to select farmers and biogas plant managers as main economic agents, and to understand the influence of long-term trust relationships in this value chain. As silage maize has been traded for many decades, and biogas plant managers entered this market several years ago, respondents were well aware of the features and challenges relating to this value chain. As a result, the interviews largely consisted of anecdotal experiences. During interviews on corn stover value chain development with Flemish stakeholders, we were able to single out farmers, custom harvesters, biogas plant managers and a potential manager of a cellulosic sugar production plant as main economic agents. Furthermore, we were able to identify the main influencing concerns and circumstances that could enhance or constrain these stakeholders from participating in such a value chain. However, as a corn stover value chain is virtually non-existent in Flanders, stakeholders merely needed to rely on assumptions rather than on their own experiences, which constrained attempts to gain a thorough and in-depth understanding of the possible organisational challenges.

In order to translate these behavioural rules into equations and algorithms, we returned to the literature. For the research on the silage maize market, we relied on previous work conducted by Klos and Nooteboom (2001) on how to model trust relationships. For the research on corn stover value chain development, we relied on the work of Jager (2001), who introduced the consumat approach as a meta-model of different expert-theories of human behaviour (Jager et al. 2000), and van Duinen *et al*. (2016) who applied this approach in a more practical context.

Hence, using the qualitative insights from the semi-structured interviews, we were able to identify the most important economic agents for inclusion in the model and deduce behavioural rules, which could then be used to develop the agent-based models.

2. <u>Contribution of the ABM results to the qualitative research</u>

While the results from the qualitative research contributed to the development of our agent-based models, vice versa, the results of the agent-based models contributed to a deeper understanding of the qualitative insights from the semi-structured interviews. More specifically, using scenario analysis, the agent-based models presented in chapters 2, 3, and 4, brought to light and increased our understanding of the different mechanisms contributing to the organisational challenges of local maize value chains in the context of the biobased economy.

First, in chapter 2, the semi-structured interviews concerning the silage maize market allowed us to understand this market and to deduce behavioural rules. After analysing the interviews, we identified four contextual factors that define the particular setting in which biogas plant managers need to operate and which might contribute to the difficulties in obtaining a stable and affordable supply of local silage maize: (1) different unit of transaction; (2) different safeguard measures; (3) the related price uncertainty; and (4) late entry into the already existing silage maize market. With the help of a scenario-analysis using the ABM, we were able to assess the relative contribution of contextual factors (2) and (4) to the difficulties experienced by the biogas plant managers. While the results of the qualitative research suggested that investing in trust relationships may be a good way to address contextual factor (2), the results of the quantitative scenario analysis revealed the limited contribution of this contextual factor. Hence, we concluded that investing in trust relationships is not worth it, as it does not significantly reduce silage maize prices, nor does it affect price volatility. On the other hand, the relative contribution of late entry into the already existing market was found to be significant.

Secondly, as stated before, during the qualitative research presented in chapters 3 and 4, we observed that the Flemish stakeholders were only able to reflect on the challenges and drivers of a potential corn stover market in a limited way and largely needed to rely on assumptions. Hence, organisational challenges were difficult to deduce solely from qualitative research. However, with the help of the ABMs, we could gain insight into the mechanisms that could potentially enhance and hamper corn stover value chain development in Flanders. For example, we were able to reveal the key, yet vulnerable, position of the custom harvesters; how governance structure influences fluctuations in farmers' participation in the corn stover value chain; and the influence of processing scale and competition in the development of a corn stover value chain. Furthermore, we could demonstrate the complexity and interlinkage of these mechanisms and how agents adapt to these, giving rise to non-linearity in farmers' participation rate and corn stover supply.

Hence, in the three cases, agent-based modelling increased our understanding of the complex adaptive system and the local biomass value chains, which could not be obtained from semi-structured interviews alone. When the interviewees were well aware of the organisational challenges, agent-based modelling allowed us to assess the relative importance of each of the challenges identified. When interviewees were less aware of the organisational challenges, agent-based modelling allowed us to gain a more thorough and in-depth understanding of the mechanisms and even to identify new ones. This "cross-fertilization" between qualitative research using semi-structured interviews and simulations using agent-based modelling was also recognized by Neumann (2015, p.1)

3. Contribution of the qualitative research to contextualizing the ABM results

As explained in the previous section, the results of the scenario analyses, using agent-based models, improved our understanding of the underlying reasons and mechanisms contributing to the challenges experienced by the different stakeholders involved in local maize value chains. However, the models were unable to provide specific strategies to address the challenges experienced.

Therefore, we went back to the semi-structured interviews conducted in Flanders having the insights gained from the agent-based models in mind. For example, in chapter 2, we found that regardless of whether the biogas plant manager builds up trust relationships with the farmers, this has no effect on the prices paid, or on their volatility. As such, we concluded that the gains resulting from investing in trust relationships with individual farmers do not outweigh the costs. As our model was not suitable to come up with mitigation strategies, we decieded to go back to the semi-structured interviews having the insights gained from the model in mind. As such, we could identify different strategies, including working with intermediaries and supporting a flexible input supply, which is further detailed in the discussion of general research question 3.

Analysing the semi-structured interviews and agent-based models dealing with the potential of a corn stover value chain in Flanders, we were able to identify organisational challenges relating to this value chain. As there was limited experience with corn stover in Flanders, conducting some additional qualitative research in a region where a corn stover value chain has been developed (i.e. Ontario) yielded some supplementary insights into how such a value chain could be developed in practice. In order to learn from the experiences in Ontario, and address the potential organisational challenges identified in Flanders, the integrated analytical framework developed by Lamprinopoulou *et al*. (2014) (Lamprinopoulou et al. 2014), was used to analyse the semi-structured interviews conducted in both regions. The findings of this analysis are discussed in chapter 5 and below.

Hence, after analysing the results of agent-based models based on qualitative insights obtained from semi-structured interviews, sometimes it can be useful to go back to these interviews or conduct additional interviews to further contextualize and consolidate the insights. Furthermore, we found it useful to present the model details and its results to the stakeholders, as this triggered discussion about the way new local biomass value chains should be organised. However, as stated before, more research is needed to confirm this finding.

Overall, using a combination of semi-structured interviews and agent-based modelling, the interplay between the qualitative and quantitative approach allowed us to gain a better understanding of the different mechanisms that contribute to the difficulties of biogas plant managers in obtaining a stable and affordable supply of local biomass and to the drivers and challenges associated with developing a corn stover value chain. This was also recognized by Pluye and Hong (2014), who warned that only using one method, either quantitative or qualitative, entails the risk of overlooking important insights. This mixed-method approach responds to the statement by Holland (2006), who suggest that “there is value in taking a cross-disciplinary approach to the study of CAS” (Holland 2006, p.3), and helps to address the lack of integrating empirical qualitative data in ABM and the study of CAS (Boero & Squazzoni 2005).

6.4 Recommendations for practitioners and policy makers

General research question 3: Given the CAS lens and using the proposed mixed method approach, what are the mechanisms behind the organisational challenges associated with value chains for local biomass in the context of a biobased economy and how can these challenges be addressed?

Investigating local biomass value chains as CAS, by using the mixed-method approach, including semi-structured interviews and agent-based modelling, allowed us to identify the mechanisms behind the organisational challenges associated with these value chains in the context of the biobased economy. These were: a late entry into the already existing market; insecure input supply; and a lack of funding when developing new local biomass value chains. Below, we discuss these challenges and present five recommendations for practitioners and two recommendations for policy makers on how to address them.

6.4.1 Challenge 1: Late entry into already existing market

“*For such a biogas [installation], you really need to expand a network of custom harvesters and through these custom harvesters [a network of] farmers”* (Biogas plant manager)

The first challenge we identified in this chapter was a late entry into an already existing market. Indeed, in chapter 2, we found that the main reason behind the difficulties of biogas plant managers in obtaining a stable and affordable supply was late entry into an already existing silage maize market. We also found that regardless of whether the biogas plant manager builds up trust relationships with the farmers, this has no effect on the prices paid by both actors, or on their volatility. As the costs relating to the development of trust relationships could be significant due to the time and resources that need to be invested, we concluded that the gains resulting from investing in trust relationships with individual farmers do not outweigh these costs.

These conclusions suggest that the biogas plant manager is trapped in this unstable supply. However, while investing in trust relationships with individual farmers might not be worthwhile, during semi-structured interviews different respondents indicated how they dealt with this deadlock situation. As indicated in chapter 2, the biogas plant managers are newcomers in a market with distinct characteristics. Therefore, knowledge of the specific context of the local silage maize market and institutional arrangements, as well as having an idea about the prices, is crucial. As a new entrant in such a market, this kind of information is not easily obtained. Therefore, several biogas plant managers indicated that they worked with intermediaries, who are often custom harvesters, or forage traders. As frequent visits to many different farmers are inherent to their job, these intermediaries usually have a very large network which they have been building for years, and a very good knowledge of the market. For example, they have a good idea about the current local silage maize prices and they know which farmers have a silage maize surplus or deficit. Additionally, they know the farmers personally, and are trusted by them. Therefore, by working with such intermediaries, the biogas plant managers can somehow “undo” their late entry. In addition, transaction costs are significantly reduced, as only two contracts need to be negotiated, instead of negotiating with each individual farmer.

This strategy of working with intermediaries who have knowledge of the market can also be observed in other biobased economy value chains. For example, interviews conducted with a company producing bioethanol from corn grains and wheat, revealed that this company is in fact governed by a set of shareholders, each of whom is specialized in a different segment of the value chain. The largest shareholder is specialized in the trade of ethanol of all kind of qualities, worldwide. As such, this shareholder knows the ethanol sales market. Another shareholder is specialized in the trade of grains, including corn grains and wheat, and the production of animal feed. Hence, this stakeholder has both knowledge on the prices and logistics of the input streams, as well as of the output stream of the by-product, dried distillers grains (DDGS), which can be used as animal feed. The last two shareholders are specialized in the trade of grains, especially wheat. They too act as a trader in the by-product DDGS.

Hence, when entering an existing biomass market, especially when it is characterized by distinct trading rules, a successful strategy is to work with intermediaries or shareholders who already have knowledge of the market.

6.4.2 Challenge 2: Insecure input supply

The second main challenge we identified was the insecure input supply for biomass processors when new biomass value chains are being developed. As demonstrated throughout this dissertation, the CAS nature of biomass value chains implies that they are characterised by non-linearity, resulting from the individual decisions of the agents in the system. As such, local biomass supply chains always face the risk of non-linear local biomass supply fluctuations, as they are inherent to the system. we present four recommendations: (1) be flexible, (2) make a well-considered choice about governance structure, (3) get all stakeholders involved and (4) create trust and enthusiasm for the new value chain.

(1) From the simulation results and the qualitative research, we recommend biomass processing facilities to allow for input flexibility.

In the ABMs presented in chapters 2, 3 and 4, we focus on only one type of input, namely silage maize or corn stover, going to one or multiple processors, namely dairy farmers, biogas plants or a cellulosic sugar production plant. We made this choice in order to be able to focus on gaining insight into the mechanisms behind the insecure input supply. However, we acknowledge that biomass producers, as well as biomass processors, do not operate in a vacuum, where only maize or corn stover is traded. Maize can also be used for other purposes (as indicated in chapter 1) and processing facilities can make use of other biomass sources.

Firstly, producers can increase their flexibility by planting dual-purpose varieties, fit for corn grain harvest as well as silage maize production. This was also recognized by the farmers during the semi-structured interviews and discussed in chapter 2. As such, depending on the yields, weather conditions, prices and other influencing factors, farmers have the ability to decide how they will harvest the maize and which market they will participate in towards the end of the growing season. It is for this reason that farmers are usually reluctant to sign long-term contracts with processors. In order to respect this desire to stay flexible, processors should preferably not impose strict quality requirements or variety obligations. This recommendation is further strengthened by the fact that on a market scale, a processor is usually too small to be able to influence the market.

Secondly, it is also important for the processors to retain an adequate level of flexibility. Biogas plants usually process a mix of silage maize, organic biological waste and manure. Within certain constraints, they are able to vary their input volumes according to the prices. If a corn stover value chain were to be successfully developed in Flanders, this might give them an extra feedstock, thereby increasing their flexibility. For a large-scale plant, such as a cellulosic sugar production plant or bio-ethanol plant, input flexibility is also important. For example, bio-ethanol plants can run both on corn grain and wheat, allowing them to respond to price fluctuations, and the cellulosic sugar production plant in Ontario will therefore not just run on corn stover, but also on wheat straw and, if necessary, wood chips.

Thirdly, a certain level of flexibility is also recommended during the development of a new value chain. Indeed, in chapter 5, we discussed how the value chain setting in Sarnia was adjusted several times, as deemed necessary. For example, originally, the developers planned a processing facility of 250,000 ton DM of corn stover per year, which was later downscaled to 75,000 ton DM.

(2) Another way of dealing with the risk of largely fluctuating local biomass supply, is to address the agents' decision making and interactions, aiming to reduce the risk of non-linear behaviour. In order to achieve this, we recommend practitioners to make a well-considered choice regarding the governance structure used. As demonstrated in chapter 4, the governance structure used to organise the corn stover value chain, largely influences its development, with spot market and "request-for-purchase" governance structures showing a greater fluctuating biomass supply than the cooperative governance structures. In deciding on the governance structure, it is important that this structure reflects the aspirations of the different stakeholders, and takes into account the contextual settings. For example, the bioprocessing cooperative established in Ontario, reflects the desire of the farmers to actively participate in the corn stover value chain, instead of just being commodity suppliers. As one farmer stated: "*Rather than just get the corn stalks and sell them to them, we said 'no we want a piece of the action'.*" Through the cooperative, the farmers are shareholders in the plant and share in the profits, enabling them to capture some of the upstream value of the sugars produced. On the other hand, farmers do not want to lose their independence over the corn grain, because it remains their most important product. Therefore, it was decided that the cooperative would only step in after the grains have been harvested, which reflects back to maintaining an adequate level of flexibility, as discussed previously. Furthermore, by letting farmers become shareholders in the plant, they gain a sense of ownership and responsibility towards the plant, encouraging them to provide a stable and high quality supply. Indeed, as they share in the profits, it is in their best interest that the plant is fully operational and produces as much sugar as possible. As such, the likelihood of opportunistic behaviour by the farmers is reduced. Furthermore, a cooperative seems a good way to avoid a gridlock situation in which farmers demand a higher corn stover price than the processors are prepared to pay. Moreover, inherent financial risks relating to the development of the new value chain can be partly attenuated by a cooperative governance structure, as the financial risk is shared between a large number of farmers and some private investors. Finally, cooperatives are a well-known

governance structure in Canada. Hence, farmers and industry are familiar with the rules, benefits and downsides, making it easier to get the idea across.

With regard to Flanders, it is difficult to assess how a corn stover value chain can be organized. The results of our ABMs suggest a spot or request-for-purchase structure will likely result in large supply fluctuations. Another option is long-term contracting, but as mentioned previously, we have the feeling that farmers are reluctant to sign such contracts, as it reduces their flexibility. Hence, in order to gain greater insight, more research should be done questioning the different stakeholders on the topic, as well as allowing them to confer with each other and come to an agreement.

(3) Another recommendation to reduce supply fluctuations is to make sure all stakeholders are involved when developing a new value chain.

As local biomass value chains are complex adaptive systems, the whole system needs to be considered. Furthermore, the individual behaviours of the actors and their interactions lead to the value chain with specific characteristics. Hence, when practitioners forget to take into account one actor or actor group, this can lead to undesirable value chain characteristics. For example, in chapter 4, the simulation results showed that insufficient corn stover supply for the cellulosic sugar production plant was due to a lack of custom harvesters investing in the appropriate harvesting equipment. Hence, they have a key position in the value chain. At the same time, they are also very vulnerable, because the fluctuation in farmers' participation rate prevents them from fully using their equipment every year. In Ontario, this key but vulnerable position of the custom harvesters was recognized. In order to address the issue, it was decided that the cooperative would invest in the harvesting equipment and hire specialized custom harvesters. This also guarantees uniformity in the harvested corn stover, making it easier for the plant to process. The need to involve farmers, and custom harvesters, as well as SMEs, was also recognized by Schmid *et al.* (2012). Furthermore, comparing the results of the in-depth case studies in Flanders and in Ontario, we found that including all stakeholders from the outset was one of the main success factors of the corn stover value chain being developed in Ontario, and the lack of it, one of the main hampering aspects in Flanders.

Over the course of this dissertation, we demonstrated how agent-based modelling in combination with semi-structured interviews can help in identifying the most influential actors on the local biomass value chain, such as the custom harvesters. Furthermore, we were able to reveal the important role of intermediaries (explained above).

Involving the different stakeholders can be undertaken in several ways. One way is to organize focus groups, in which the potential participants in the value chain can express their concerns. In Ontario, these focus groups helped to identify the challenges for farmers to participate in the corn stover value chain. Secondly, stakeholders could also be involved more directly by establishing a kind of advisory committee with representatives from the producers' side, such as farmers and representatives of farmers' organisations; custom harvesters and harvesting equipment producers; representatives from industry, including possible off-takers of the sugars; and policy makers. Establishing such an advisory committee was also recommended by Schmid *et al.* (2012). The involvement of local representatives helps to enhance local capabilities and deal with diversity and complexity (Schmid et al. 2012). Furthermore, integrating expertise from academics, practitioners, businesses and policy makers greatly increases the knowledge base (Schmid et al. 2012; EU SCAR 2012). Additionally, as observed in the Ontario case study, the establishment of an advisory committee proved to increase cooperation between the different stakeholders in the value chain. This was also identified by Schmid *et al.* (2012) as a precondition for the European bioeconomy to achieve its full potential. Such an advisory committee should preferably be guided by a proficient boundary spanning actor, such as BIC, which can create a common vision amongst the different stakeholders (Williams 2002). One way to realise this in a European context is to establish an IBO focusing on the use of cellulosic biomass for the biobased economy, as discussed in Chapter 5. While currently the support for IBOs within the CAP mainly focusses on food value chains, for the future CAP after 2020, the outcomes of our research support that such IBOs should still be incentivized by the CAP, and that these IBOs should also be established for non-food value chains with a focus on further developing the biobased economy.

(4) Finally, in order to convince farmers and custom harvesters to get involved and to increase supply security, they should have trust in and enthusiasm for the new value chain. Indeed, when developing a new value chain, such as the corn stover value chain, each stakeholder can individually decide to participate or not and the confluence of these decisions gives rise to the value chain. In order for the different stakeholders to participate in the corn stover value chain, their individual concerns need to be addressed. For example, farmers are worried about the effect of corn stover harvest on the soil organic carbon or about the possible damage to their fields when corn stover is harvested under wet weather conditions; custom harvesters have doubts about investing in the harvesting equipment, because they are unsure whether the equipment will perform even in difficult conditions; and potential off-takers need to gain trust in the quality of the products. According to Rösch and Kaltschmitt (1999), such technical and non-technical uncertainties create difficulties in obtaining loans from private banks and investment from private companies (Rösch & Kaltschmitt 1999). As such, in order to get stakeholders involved, trust needs to be created in the new value chain.

In chapter 5, we demonstrated that farmers' trust in the value chain can be enhanced by organizing harvest demonstrations, and conducting independent studies on the effect of corn stover harvest on the SOC. Furthermore, in chapter 5, the importance of working with champions was also stressed. Moreover, trust amongst the off-takers was increased by having different potential processors testing the products. Additionally, in the Ontario case study, we also found that trust in the value chain was increased by well-conducted environmental impact and risk studies. Presenting the results of these studies, including the technical and non-technical information, as well as the risks and benefits associated with the new value chain, should be done “in an adequate, objective and fair way” (Rösch & Kaltschmitt 1999, p.353).

Finally, it is also important to generate trust amongst policy makers. Indeed, policy makers need to be assured of the benefits of creating a corn stover value chain, but they also need to be convinced that the project is well executed, generating a higher chance of acquiring subsidies for further research (Rösch & Kaltschmitt 1999). In order to realize this, it is advisable to have policy makers to sit on an advisory committee, together with all the other stakeholders and to discuss openly all issues and doubts regarding the value chain. As stated in chapter 5, this might seem risky, as policy makers could start doubting the whole project. However, the Ontario case study demonstrated that by being honest about all the uncertainties and demonstrating how these uncertainties could be addressed, policy makers had even greater confidence in the project and its benefits. In this respect, an open discussion with policy makers is advised, while being aware of the timing for issuing the information and making sure the information is adequate (Rösch & Kaltschmitt 1999).

6.4.3 Challenge 3: Lack of funding to develop new value chains

In chapter 5, one of the main challenges identified for the development of a corn stover value chain in Flanders was the lack of funding. Indeed, several Flemish respondents argued that Flemish funds are rather sectoral, focusing either on agricultural innovation projects or on innovation projects for SMEs. This hampered obtaining funding for the corn stover value chain development, which includes both innovations in the agricultural sector, as well as with SMEs. While at the European level, several funds exist that support value chain initiatives, the Flemish stakeholders were unable to receive funding, despite their applications. The reasons for rejection are not perfectly clear to the authors, and may be attributed to competition or other reasons. However, we still want to stress the importance of taking a whole value chain approach when setting up funding schemes. As one of the boundary spanning actors involved in the corn stover value chain development in Ontario stated: “*You need to look at it from that whole value chain perspective of getting it to me. It goes from field, and you do not stop, the first place you should stop is at the sugars, and then work that whole circle together.”* When developing a new value chain of local biomass, such as a corn stover value chain, policy makers should be aware that these are complex adaptive systems, and thus characterised by aggregation, flows, non-linearity and heterogeneity. Therefore, there is need for a thorough understanding of all the stakeholders involved, their interactions, and how these influence the development of new local biomass value chains. Furthermore, there is need to understand all the actions that are required from the start of cultivation up to the sale of the product. For all the different steps, one needs to address the technological requirements, the logistical implications, the economic considerations and the organisational aspects, while also taking into account the aspirations of the different stakeholders. Moreover, all these aspects need to be interlinked. As such, funding should not stop at one sector, but should be inter-sectoral covering the whole value chain. As discussed in chapter 5, and also recognized by Rösch and Kaltschmitt (1999) this initial governmental funding is necessary before sufficient trust can be generated with private partners to make in-kind contributions (Rösch & Kaltschmitt 1999).

Finally, in chapter 5, we discussed the difference in mentality with regards to subsidies between Flanders and Ontario. In Flanders, it is widely believed that biobased economy value chains cannot be economically viable without subsidies. These subsidies are justified by the environmental benefits of biobased economy products, compared to the use of fossil resources (Rösch & Kaltschmitt 1999). However, in order for such subsidies to be beneficial, they should be guaranteed over the long term (Rösch & Kaltschmitt 1999), as it was found that in the biobased economy sector, an uncertain funding climate is detrimental for attracting new investment (Willeghems 2017). Conversely, in Ontario, the first prerequisite to continue the development of the corn stover value chain was to ensure that it was economically viable without subsidies. Of course, during the project itself, funding was given to conduct the different studies and to bring together the different stakeholders. Therefore, we believe that it might be worthwhile to consider shifting funds more towards subsidies that encourage new investments and the development of new value chains for the bioeconomy, rather than to keep on subsidizing biomass processing plants that are already up and running. This funding could, for example, be provided in the form of tax allowances for investments in new projects, tax reductions on the interests gained from investments in such projects, or governmental investment credits with low interest rates, or investment subsidies (Rösch & Kaltschmitt 1999).

In conclusion, we present Table 6.2, which summarizes the three main challenges identified in this dissertation and presents recommendations to practitioners and policy makers to address them.

Table 6.2 Three main challenges identified and recommendations to practitioners and policy makers to address them

Challenge	Recommendation	For whom?
1. Later entry into already existing market	Work with intermediaries	Practitioner
2. Insecure input supply	Be flexible	Practitioner
	Make well considered choice about governance structure	Practitioner
	Get all stakeholders involved	Practitioner
	Create trust and enthusiasm in the value chain	Practitioner
3. Lack of funding to develop new value chains	Value chain approach instead of sectoral funding	Policy maker
	Investment and development subsidies instead of subsidizing the production process	Policy maker

6.5 Concluding remarks and prospects for further research

The general objective of our research was to generate key insights to address organisational challenges of local biomass value chains in the context of the biobased economy. Over the course of this dissertation we were able to generate three key insights, which help in addressing such organisational challenges.

First, we found that a complex adaptive system lens is a useful approach to study organisational challenges of local biomass value chains. Indeed, using a CAS lens, we were able to take into account the diversity of the individual economic agents in the value chain, their actions and interactions that lead to the emergent phenomenon, being a market or value chain, with its specific characteristics.

Second, we found that using a mixed-method approach, including semi-structured interviews and agent-based modelling, contributed to an increased understanding of the mechanisms that lead to the organisational challenges in local biomass value chains for the biobased economy, both for us as researchers, as well as for practicioners and policy makers. In particular, the interplay between the qualitative research and quantitative modelling proved to be helpful in three ways:

(1) Insights from semi-structured interviews helped in identifying agents and behavioural rules to be included in the agent-based models
(2) Insights from the agent-based models helped to generate a deeper understanding of the qualitative insights from the semi-structured interviews. Indeed, using scenario analysis we obtained a deeper understanding of the different mechanisms that contributed to the organisational challenges of local biomass value chains in the context of the biobased economy.

(3) Going back to the semi-structured interviews and/or conducting additional semi-structured interviews after analysing the results of the agent-based models, helped us to identify possible ways to address the organisational challenges and to further contextualise and consolidate our findings.

Furthermore, by communicating our models and its results to practitioners and policy makers, by, for example, organizing a workshop, we found that they were also able to gain additional insights and that our model could serve as a tool triggering discussion on how, in our case, a corn stover value chain should be preferably organized. Hence, the mixed-method approach proved to be usefull not only to acquire insights into the organisational challenges of local biomass value chains in the context of the biobased economy ourselves, but also to increase the insights with the stakeholders.

Third, using the CAS lens and the mixed-method approach, we were able to identify three main organisational challenges of local biomass value chains in the context of the biobased economy: (1) late entry into an already existing market; (2) insecure input supply and (3) lack of funding to develop new biomass value chains.

In order to address these challenges, we formulated 5 practical recommendations for practitioners:

(1) Try to work with intermediaries, when you are a new entrant into an already existing local biomass market;
(2) Retain an adequate level of flexibility;
(3) Make a well-considered choice about governance structure, which reflects the aspirations of the different economic agents involved in the value chain;
(4) Make sure all stakeholders are involved when developing new biomass value chains in the context of the biobased economy; and
(5) Pay special attention to create trust and enthusiasm for the new value chain amongst all stakeholders involved.

Furthermore, we formulated 2 recommendations for policy makers:

(3) We advise policy makers in Flanders to set aside special funds to allow for projects that take a value chain approach; and
(4) We advise policy makers to consider to move away from operational subsidies, which often cannot be guaranteed over the long term, and go for investment and value chain development subsidies instead. Such subsidies can, for example, be provided in the form of tax allowances for investments in new projects, tax reductions on the interest gained

from investments in biobased economy projects, or governmental investment credits with low interest rates.

We believe that these three key insights are a valuable guide to further research. Over the course of this dissertation, we confirmed the importance of organisational challenges in biomass value chains in the context of the biobased economy. While research often focuses on the technical and techno-economic aspects of biomass value chains, we think more attention should be given to the organisational aspects, while taking into account the technical and techno-economic findings. Hence, in future research and future projects, not only should there be technical, techno-economic or organisational research, but there is also a need for interdisciplinary research integrating the technical, techno-economic and organisational aspects of the value chains. As such, acknowledging that such local biomass value chains are complex adaptive systems, we advocate taking a more holistic value chain approach, and to allow for greater interaction between researchers from different disciplines and stakeholders with more practical knowledge.

In this regard, the research on the potential of a corn stover value chain in Flanders could be extended by setting up an advisory committee. Involving practitioners in the research would allow their knowledge to be exploited and behavioural rules to be validated (Boero & Squazzoni 2005). In this sense, the workshop "*Maïsstro, waardevoller dan u denkt?*" provided the first step. However, more such workshops are necessary to further feed the agent-based models with more empirical data and to create trust and cooperation between the different stakeholders. Furthermore, presenting our agent-based model at this workshop and using it as a communication tool, increased the stakeholders' insights into the organisational challenges of new local biomass value chains. However, more research is needed to confirm this result.

Additionally, the use of a mixed-method approach, combining semi-structured interview and agent-based modelling, can be recommended to study local biomass value chains as CAS in order to enhance the development of the biobased economy. In our research, we decided to keep the agent-based models relatively simple, and not to include certain aspects, such as inter-year variability of corn stover yields (Golecha & Gan 2016), nor did we model all possible market mechanisms, crop choices, or investment options. Further research could aim to increase the detail of our models. However, in doing this, one needs to carefully consider its added value, as increasing model complexity may also reduce the ability of the researcher to fully understand the results. On the other hand, further research could also aim to reduce the detail in our models, making them more generally applicable to other regions or other biomass value chains. However, in doing this, the researcher should be aware that the level of detail should be sufficiently high in order to gain practical insights; otherwise the model can only yield theoretical insights. Furthermore, further research could also focus on integrating the different agent-based models developed in this dissertation.

Finally, in this dissertation we focussed on maize value chains, as a first test case for our approach. However, after evaluation, we believe our approach could also be applied to other biomass types. In this respect, we hope that our research can also stimulate researchers to study other local biomass value chains, including those for perennial crops, in order to further enhance the development of the biobased economy.

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Icons used in this dissertation

Combine Harvester, Created by Tomasz Pasternak from the Noun Project.

Corn, Created by Claire Jones from the Noun Project.

Curriculum, Created by David from the Noun Project.

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Annex A: ODD-protocol of the agent-based model presented in chapter 2

A.1. Introduction

Biogas plant managers in Flanders face increased financial uncertainty. In 2014, 10% of the Flemish biogas plants went bankrupt. The difficulty in obtaining feedstock at stable and affordable prices is one reason why the biogas sector struggles. In literature, contracting is often proposed as a way to decrease the volatility of the feedstock costs. However, these studies generally do not consider the context in which the biogas plant manager needs to buy local biomass. This context could be of specific importance when biogas plant managers are in competition with other users of the same biomass type. Silage maize is an example of such a feedstock, as it is both used by dairy farmers and biogas plant managers. Using a combination of qualitative research and agent-based modelling, we investigated the effect of specific characteristics of the silage maize market on the feedstock cost prices and the price volatility.

This document details the agent-based model we developed for the silage maize market in Flanders, using the ODD protocol. The ODD (Overview, Design and Details) protocol was developed by Grimm *et al.* (2006) in order to have a standard protocol for describing agent-based models following a general structure. (Grimm et al. 2006; Grimm et al. 2010). Silage maize is both traded amongst dairy farmers, who use it as feed and between dairy farmers and biogas plant managers, who use it as feedstock for anaerobic digestion. Therefore, we included these two markets in the model. Since silage maize can also be sold as grain, we included the grain maize market as well. Dairy farmers and biogas plant managers that are not able to purchase enough silage maize to meet their demands, are forced to buy alternative feed or feedstock.

A.2. Overview

A.2.1. Purpose

The agent-based model, developed in Netlogo (Wilensky 1999), was designed to obtain information about the influence of the market context on the ability for biogas plant managers to purchase local biomass for anaerobic digestion. In particular we wanted to gain insights on the effect of a late entry and the use of institutional arrangements by biogas plant managers in comparison with dairy farmers. The agents in the model are boundedly rational; besides seeking for revenue maximization (silage maize suppliers), or feed(stock) cost minimization (silage maize buyers), agents also take into account trust relationships they build up over the years.

A.2.2. State variables and scales

A.2.2.1. Structure of the model system

The goal of the model is to simulate the silage maize market amongst dairy farmers and between dairy farmers and a biogas plant manager. Since these markets are influenced by the markets of alternative feed and feedstock and the grain maize market, these markets are also included in the model. The goal of the model was not represent reality, but merely to gain insights into the market mechanisms. Figure A.1 shows a schematic overview of the model.

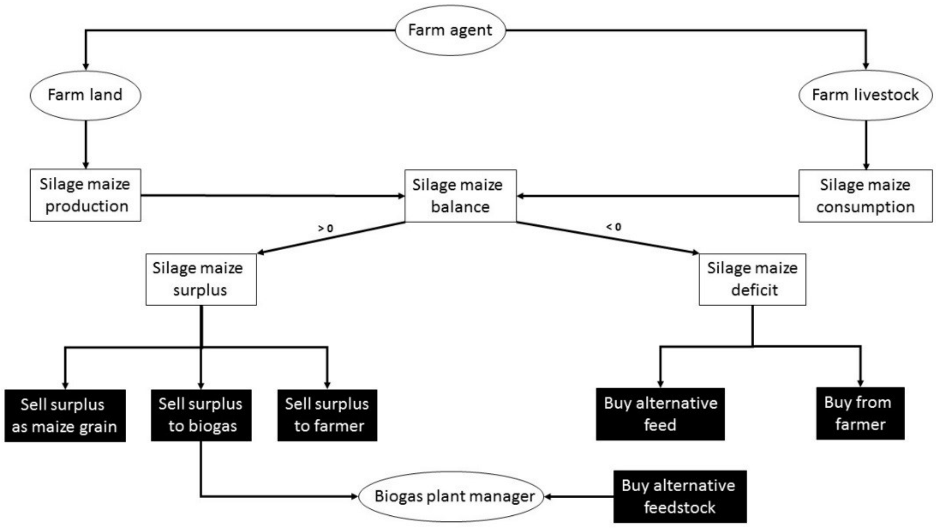


Figure A.1 Schematic overview of the agent-based model. The farmers' and biogas plant manager's different decision possibilities included in the model are indicated with a black background.

A.2.2.2 Markets

The model includes two markets that are explicitly modelled and that can be influenced by the agents:

- The silage maize market amongst dairy farmers
- The silage maize market between dairy farmers and a biogas plant manager.

Three markets are implicitly modelled. Although some agents are active on these exogenously determined markets, no interactions are explicitly modelled and the agents cannot influence them. Prices in these markets are exogenously determined, however, the prices fluctuate over time. This will be explained later in the document.

- The maize grain market
- The market of alternative feed for dairy farmers
- The market of alternative feedstock for anaerobic digestion.

A.2.2.3. Agents

Dairy farmers and a biogas plant manager are the two main agent types included in the model. Grain traders and suppliers of alternative feed and alternative feedstock are not involved in direct interactions with the agents. Table A.1 shows an overview of the two explicitly modelled agent types and their attributes. We used the data of specialized dairy farmers available in the FADN database for the silage maize surfaces and the number of dairy cows. With regard to

Table A.1 Overview of the explicitly modelled agent types and their attributes

Agent type	Attribute
Farmer	Location Surface to grow maize (ha) Yield (ton dry matter (DM) /ha) Number of cows (-) Silage maize consumption per cow per year (ton DM/cow/year) Trust factor (-) Weight the agent attaches to making profit (-)
Biogas plant manager	Location Silage maize demand per year (ton DM/year) Trust factor Weight to agent attaches to making profit (-)

The agents are located in a square of 400 km² , which is about the size of five high density dairy farming municipalities in Flanders. The dairy farmers are randomly located in this square. Square plots of 1 km² are the basic spatial units. The shape of the agent gives an indication on the state of the dairy farmer:

- A circle represents a dairy farmer with a silage maize surplus
- A square represents a dairy farmer with a silage maize deficit.

Since the biogas plant manager has no land available for silage maize, he always has a shortage of silage maize. The biogas plant is always located in the center of the simulated area and is indicated with a red target sign. The figure below shows the modelled area in a typical configuration.

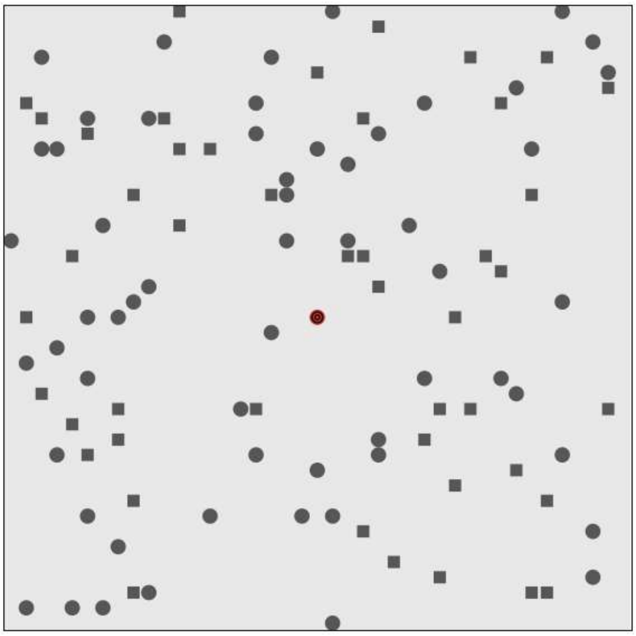


Figure A.2 Representation of the modelled area in a typical configuration before the start of the simulations. The circles represent farmers with a silage maize surplus, the squares farmers with a silage maize deficit. The target sign in the centre of the modelled area represents the biogas plant.

The model proceeds in annual time steps over a period of 16 years. There are no hierarchical levels in the model, meaning that all agents operate at the same level. Finally, several auxiliary variables are included in the model. The information that is contained in these variables is available to all agents in the model. The auxiliary variables are:

- Total maize balance (ton DM)
- Maize grain price (€/ton DM). These prices follow the historic maize grain prices of the period between 1999 and 2014 (IndexMundi 2014).
- Price of alternative feed (€/kVEM and €/kDVE)
- Price of alternative feedstock
- Weather conditions

A.2.3. Process overview and scheduling

Figure A.3 shows a schematic overview of the different model procedures. These can be subdivided into three large sections: the setup, the actual model, and the generation of output results. These three sections will be discussed below.

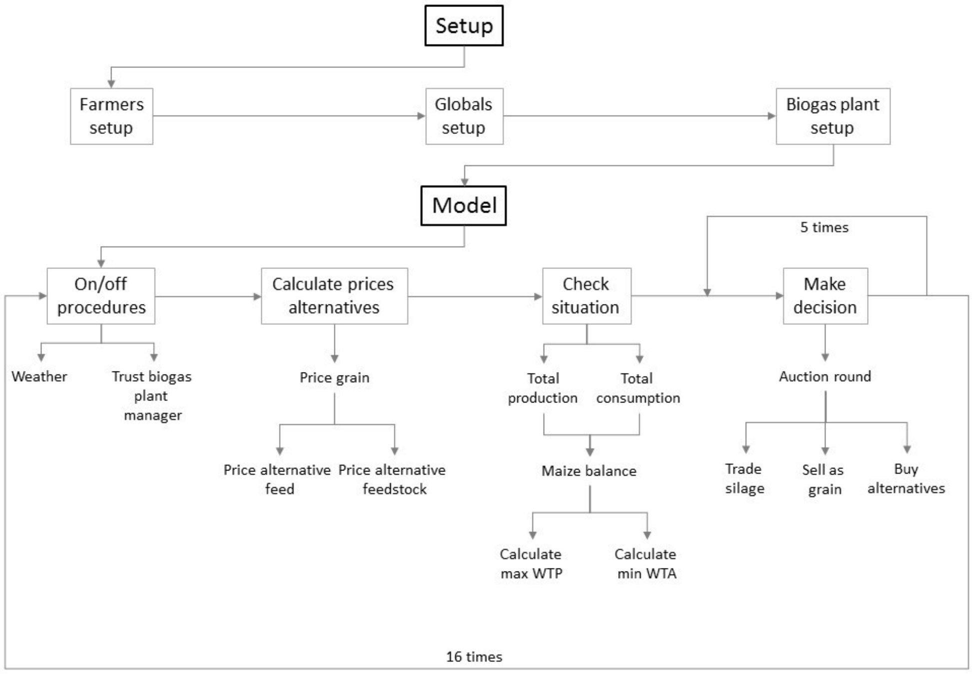


Figure A.3 Schematic overview of the different model procedures

A.2.3.1 Setup

At the start of the each simulation, a setup is executed which initializes the simulation environment. The farmers (farmers setup), the auxiliary variables (globals setup) and the simulation environment (patches setup) are always set up at the start of the simulations. The biogas plant setup is only executed at the moment the biogas plant is introduced in the market.

A.2.3.2. On/off procedures

Several procedures in the model can be activated or deactivated in order to assess their influence on the model results. One such procedure is the weather-procedure. When the weather procedure is on, the weather value varies randomly each simulation run between 0.8 and 1.2, simulating large yield in case of good weather conditions and low yields in case of bad weather conditions. When this procedure is turned off, the weather value stays fixed at 1 and there are no yield fluctuations. The other procedure is the trust procedure by the biogas plant manager. When the procedure is on, the biogas plant manager is able to build up trust relationships with his suppliers. If the procedure is off, the biogas plant manager is not able to build up trust relationships. Dairy farmers always build up trust relationships with their suppliers.

A.2.3.3. Calculate prices alternatives:

In this procedure, the grain maize price is adjusted to the modelled year (IndexMundi 2014) (Figure A.4). Prices of feed for dairy cows can be related to these prices of maize grain, by means of a price for their energy component (kVEM) and their protein component (kDVE).

Using the kVEM, kDVE and grain maize prices published by Wageningen UR (Wageningen UR Livestock Research 2014), we found a linear relationship between the NEL price and the maize grain price. Therefore in this procedure we calculate the NEL price using this relationship. However, we found no correlation between the maize grain price and the kDVE price. Therefore, it was decided to randomize this price variation following a triangular distribution between 0.73 €/kDVE and 1.37 €/kDVE. The price for alternative feed is than calculated based on the NEL price and the kDVE price (Animal Sciences Group WUR 2006). For anaerobic digestion, only the energy component is of interest. Therefore the feedstock prices are calculated based on the kVEM price.

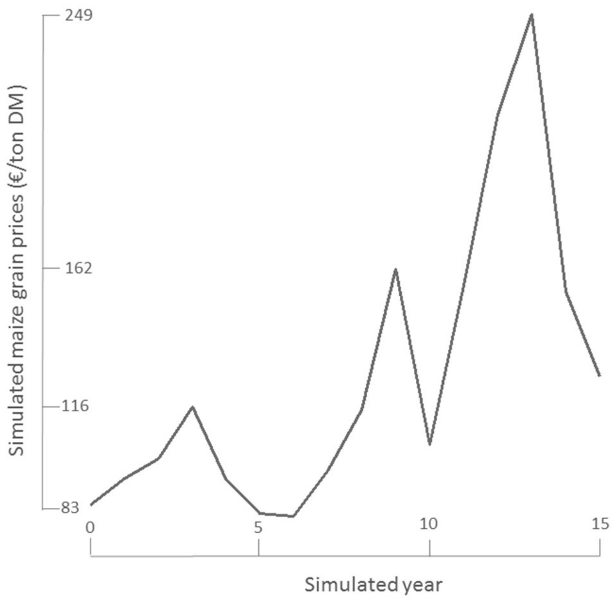


Figure A.4 September maize grain prices between 1999 and 2014

A.2.3.4. Check situation module

In this procedure all agents calculate their total silage maize production, taking into account the weather conditions. Since the biogas plant manager has no land available for the production of silage maize, his total silage maize production is always equal to zero. Next, the farmers calculate how much silage maize they need per year (ton/year), based on the number of dairy cows they have and the average silage maize consumption of a dairy cow per year. For the biogas plant manager the total silage maize consumption is fixed at 3000 ton DM/year. By comparing the yearly silage maize production with the yearly consumption, agents calculate whether they have a shortage or a surplus of silage maize. Based on this knowledge, they adjust their status to 1 if they have a surplus and to 2 if they have a deficit.

Farmers with a silage maize deficit calculate the maximum willingness to pay (WTP) (expressed in €/ha) for silage maize for farmer based prices of alternative feed, the average silage maize yield, the weather value and the harvest costs. The maximum WTP of the biogas plant manager is the price of the alternative feedstock, expressed in €/ton DM, as he purchases his silage maize in tons delivered at the biogas plant site. Farmers with a silage maize surplus calculate the minimum willingness to accept for one hectare of silage maize (expressed in €/ha), based on grain prices, the grain yield and the weather value.

A.2.3.5. Make decision module

After the agents have determined their status, they need to make a decision regarding the sale or purchase of silage maize or alternative feed or feedstock. The model assumes feed(stock) cost minimizing behavior for agents with a silage maize deficit and a revenue maximizing behavior for agents with a surplus. In order to include bounded rational behavior and the development of durable relationships in the model, agents make their decisions by calculating a score, which was derived from the Cobb-Douglas function proposed by Klos and Nooteboom (Klos & Nooteboom 2001). The score can be interpreted as a trade-off between minimal feed(stock) costs or maximum revenue and staying loyal to previous trading partners. As agents trade more often with each other, the loyalty between them gradually increases and becomes more important when calculating the score. Agents with a silage maize deficit only make offers to the farmers with the highest score. The offer is calculated based on the maximum WTP minus the transportation cost to the possible trading partner. As agents do not want to offer their full maximum WTP, they multiply this with a Cr-factor (explained in more detail below). Agents with a silage maize surplus only accept offers from agents with the highest scores. When the offer of the agent with the highest score is less than what they can gain from selling the surplus as grain, the farmer will decide to sell all its surplus on the grain market. Finally, agents that were not able to purchase all the necessary maize from a farmer, will be obliged to buy alternative feed(stock), and vice-versa, farmers with a silage maize surplus that could not sell all their surplus to another agent will sell this surplus on the grain market.

Finally, the simulations end after 16 runs, representing a period of 16 years.

A.3. Design concepts

A.3.1. Basic principles

We based the design of our model on the information we obtained from semi-structured interviews with experts and other stakeholders in the silage maize market, including dairy farmers, biogas plant managers and intermediary persons. The focus of this model is to simulate the trade of silage maize amongst dairy farmers and between dairy farmers and biogas plant managers in order to assess the influence of a late entry and of the use of different institutional arrangements on the purchase of local silage maize for anaerobic digestion. In the model we assume feed or feedstock cost minimizing behavior for agents with a silage maize deficit. Farmers with a silage maize surplus pursue a revenue maximizing behavior. These purely rational behaviors are attenuated by introducing trust relationships which affect the agents' decision making.

A.3.2. Emergence

The model allows us to observe the silage maize market that emerges under different scenarios. This allows us to test the effects of a late entry in the market or the use of different institutional arrangements on the local silage maize prices paid by biogas plant managers compared to farmers. More specifically, we look for the effects on the silage maize prices and the price volatility experienced by biogas plant managers and farmers.

A.3.3. Adaptation

Each agent experiencing a deficit of silage maize has a maximum amount of money he wants to spend on one hectare (farmers) or ton (biogas plant managers) of silage maize. This maximum amount of money, or the maximum willingness to pay is based on the price of the alternative feed, the transportation costs and the harvest costs. Since the agents do not want to pay too much, they reduce their maximum offer by multiplying it with a Cr-factor, in analogy with Shastri *et al.* (2011). This Cr-factor is calculated using following formula's and is updated each auction round:

$$Cr = 1 - \nu^5 \tag{A1}$$

$$\nu = max[\frac{n}{N}, \frac{t}{T}] \tag{A2}$$

with n the amount of silage maize the agents were already able to purchase, N the agent's total demand (N), t the number of auction rounds before the season is over and T the total number of bidding rounds.

A.3.4. Fitness

Fitness is not included explicitly in the model

A.3.4. Prediction

Prediction is not modelled explicitly in the model.

A.3.6. Interaction

Direct interaction between agents takes place when they trade silage maize. In the first step, agents with a silage maize deficit send an offer to farmers with a silage maize surplus. Which agent they will send an offer to depends on the score they attach to each farmer with a silage maize surplus. This score is calculated as a Cobb-Douglas function making a trade-off between buying silage maize at the best price and staying loyal to previous trading partners. How many farmers they will send an offer to depends on the ratio between the amount of silage maize they are asking and the total silage maize deficit over all farmers. If the ratio is small, they will send an offer to few farmers. If the ratio is large, they will send their offer to more farmers. We made this assumption, because farmers with large silage maize deficit are more inclined to find trading partners than farmers with a small deficit. In the second step, farmers with a silage maize surplus compare their offers with the revenue they could make by selling their maize as grain. If the offers are lower, they sell their surplus as grain. If the offers are higher, they sell their maize to the farmer with the highest score. Similarly to farmers with a silage maize deficit, this score is calculated as a Cobb-Douglas function making a trade-off between selling silage maize at the best price and staying loyal to previous trading partners.

A.3.7. Sensing

Agents know the price for grain maize, alternative feed and alternative feedstock, the transportation costs and the harvest costs of silage maize. They also know which farmers have a silage maize surplus and which farmers have silage maize deficit.

A.3.8. Stochasticity

There are several state variables that are randomly initialized:

- Dairy farmers are randomly located over the simulated area.
- Dairy farmers are assigned a random silage maize yield ranging between 15.4 and 20.6 ton DM per hectare, a grain maize yield ranging between 9.3 and 13.3 ton DM/ha and a yearly consumption of silage maize per dairy cow ranging between 2.5 and 3 ton DM per year. All parameters follow a triangular distribution. The parameters do not change over time.
- Dairy farmers are assigned a random value for the weight they attach to making profit as opposed to staying loyal to their previous trading partners. We made the assumption that all farmers attach a significant value to making profit, therefore this number ranges following a triangular distribution between 0.5 and 1. This parameter does not change over time.
- Dairy farmers are given a trust factor, which determines how fast they build up trust relationships. This parameter follows a triangular distribution between 0 and 1. The trust factor does not change over time.

- Initial friendships between the agents are determined by the base level trust. For friendships amongst farmers, this parameter is randomly allocated and ranges between 0.3 and 0.9. We assumed that no farmer really knows the biogas plant manager, since he is a new entrant in the market. Additionally, some farmers are more reluctant to sell their maize to a biogas plant than others. Therefore, between the biogas plant manager and the dairy farmers, the base level trust parameter varies randomly between 0 and 0.5. Friendship values do not change over time.

Additionally, weather variations were included in the model. Good weather conditions (weather-value > 1) will increase the maize yield, while bad weather conditions (weather-value < 1) will reduce the maize yields. The weather-value is assigned randomly at the start of each run and ranges between 0.8 and 1.2.

Finally, price of the protein component of the feed for dairy cows is randomly determined at the start of each run and ranges between 0.73 € and 1,37 € per kilo following a triangular distribution. The price of maize grain, transportation costs and harvest costs are exogenous parameters in the model. They influence the farmers decision behavior, but they cannot be altered by the agents during the simulations.

For each simulation round, the random seed was registered. This allows us to reproduce the results if necessary.

A.3.9. Collectives

Depending on their maize balance, agents are split up into agents with a silage maize surplus and agents with a silage maize deficit. Agents can have a different status in different years, e.g. when weather conditions are bad, a farmer that normally has a silage maize surplus can be faced with a silage maize deficit. The status of the agents determines their decision possibilities.

A.3.10. Observation

Following output is generated by the model:

- The average value of the weight silage maize suppliers attach to making profit. This was calculated for the suppliers to dairy farmers with a silage maize deficit and suppliers to the biogas plant. The value gives insight in the way more loyal suppliers behave as opposed to more opportunistic farmers.
- Another output is the average of the price volatility experienced by the dairy farmers and the biogas plant manager. We calculated this price volatility as the standard deviation of the prices paid over the full simulation period, representing 16 years, for

the prices of grain maize, silage maize, alternative feed and alternative feedstock. In order to compare the differences between dairy farmers and the biogas plant manager, we calculated the averages of these price volatilities separately for the two agents types.

- As a final output we also calculated the average prices paid by the dairy farmers and the biogas plant manager for silage maize.

All these data were calculated each simulation run and then stored into a csv-file. The resulting csv-file was then analyzed using Excel and R. We included data of all agents for the analysis.

A.4. Details

A.4.1. Initialization

At the start of the simulations, agents are randomly located in the simulated area. Furthermore, the farmers are initialized with a weight they attach to making profit as opposed to staying loyal and a value that determines the rate at which they build up trust relationships, a silage maize yield and a grain maize yield, and a yearly consumption of silage maize per dairy cow. A friendship value between farmers is also initialized at the start of the simulations.

The exogenous variables (transportation costs, harvest costs, the cost of the agricultural contractor, and the volume of the transportation cart) are initialized based on the results from the semi-structured interviews and literature.

A.4.2. Input

For the prices of the maize grain, we took the historic maize grain prices of the period between 1999 and 2014 (Wageningen UR 2014). The prices of the energy component of the silage maize and the prices of the alternative feedstock are linearly correlated to these prices. Data for the number of dairy cows per farmer as well as the amount of hectares available for the cultivation of silage maize were retrieved from the FADN database of 2012.

A.4.3. Submodels

The model has the following structure. In total there are four main modules which are in turn split up into different procedures. The first two modules are included mainly for computational reasons. The following two modules are the core of the model, in which the agents calculate whether they have a silage maize surplus or a deficit and make decisions on the sale or purchase of the silage maize.

A.4.3.1. On-off-procedures:

The following procedures are included to be able to include or exclude certain variations of parameters or behavioral rules.

1. Weather: When the weather procedure is on, the weather value varies randomly each simulation run between 0.8 and 1.2, simulating large yield in case of good weather conditions and low yields in case of bad weather conditions. When this procedure is turned off, the weather value stays fixed at 1 and there are no yield fluctuations.
2. Trust biogas plant manager: When the procedure is on, the biogas plant manager is able to build up trust relationships with his suppliers. If the procedure is off, than the biogas plant manager is not able to build up trust relationships. Dairy farmers always build up trust relationships with their suppliers.

A.4.3.2. Calculate prices alternatives:

In this procedure the prices for alternative feed and feedstock are calculated based on the maize grain price of that year. These prices are the historic maize grain prices between 1999 and 2014 (IndexMundi 2014). For dairy cows, both the energetic value (kVEM) as well as the proteins (kDVE) of the silage maize is important. The price of the alternative feed is calculated using following equation, taken from literature:

$$P_{alt.feed} = 0.950 * price_{kVEM} + 0.058 * price_{kDVE} \quad \text{(A3)}$$

The energy price for dairy cows (€/ kg NEL) is linearly correlated to the price of the grain maize:

$$price_{kVEM} = 0.10152 * price_{maize.grain} - 8.426 \quad \text{(A4)}$$

As mentioned before, the prices of the proteins are randomly assigned. The price for alternative feedstock (€/ton) for biogas plants is linearly correlated to the price of the grain maize prices using following equation:

$$P_{alt.feedstock} = \frac{0.10152 * price_{maize.grain} + 7}{0.2} \quad \text{(A5)}$$

As can be observed, this is largely the same equation as the NEL price. However, it was corrected in order for the prices to fluctuate around 20 €/ton as was indicated by one of the respondents.

A.4.3.3. Check-situation-module

1. Calculate total silage maize production: Dairy farmers first calculate their total silage maize production (ton/year) based on the number of hectares ($surface_{silage}$, expressed in ha) and on their yield ($yield_{silage}$, expressed in ton DM/ha). This total production is adjusted with the

help of the weather value, simulating high yields in case of good weather conditions and low yields in case of bad weather conditions.

$$total\ silage\ maize\ production = yield_{\ silage} * \ surface_{silage} * weather - value \tag{A6}$$

2. Calculate total silage maize consumption: Next, the farmers calculate how much silage maize they need per year (ton DM /year), based on the number of dairy cows they have and the average silage maize consumption of a dairy cow per year ($consumption_{silage}$, expressed in ton DM/year).

$$total\ silage\ maize\ consumption = number\ cows * consumption_{silage} \tag{A7}$$

For the biogas plant manager the total silage maize consumption is fixed at 3000 ton DM/year.

3. Calculate maize balance: By comparing the yearly silage maize production with the yearly production, agents calculate whether they have a shortage or a surplus of silage maize. Based on this knowledge, they adjust their status to 1 if they have a surplus and to 2 if they have a deficit.

$$Maize\ balance = total\ silage\ maize\ production - total\ silage\ maize\ consumption \tag{A8}$$

If maize balance > 0: status = 1

If maize balance < 0: status = 2

4. Calculate maximum WTP: all farmers with a silage maize deficit calculate the maximum price they are willing to pay (maxWTP, expressed in €/ha) for one hectare of silage maize based on the price of alternative feed(stock) and the harvest costs:

$$maxWTP = (P_{alt.feed(stock)} * yield_{silage} * weather - value) \tag{A9}$$

For the biogas plant manager, the maxWTP is expressed in €/ton DM and is the price of the alternative feedstock, expressed in €/ton DM, as he purchases his silage maize in tons delivered at the biogas plant site.

5. Calculate minimum WTA: agents with a silage maize surplus calculate the minimum willingness to accept for one hectare of silage maize (expressed in €/ha), based on grain prices, the grain yield and the weather value.

$$minWTA = \ (P_{maize.grain} * yield_{silage} * weather - value) - harvest.costs \tag{A10}$$

A.4.3.4. Make decision current year module

The agents need to make a decision regarding the sale or purchase of silage maize or alternative feed or feedstock. The model assumes feed(stock) cost minimizing behavior for agents with a silage maize deficit and a revenue maximizing behavior for agents with a surplus. However, we also included bounded rational behavior through the introduction of trust relationships. The trade of silage maize is simulated as a sealed bid auction repeated multiple times in order to simulate a negotiation process.

First the agents calculate the Cr-value. Next, the agents calculate the relative additional costs of the purchase of alternatives compared to the purchase of silage maize from a particular agent with a silage maize surplus

$$\mathrm{Relative.additional.cost_{ji}} = \frac{\mathrm{yield_{silage}} * \mathrm{P_{alt.feed(stock)}} * \mathrm{volume_{ji}}}{\mathrm{percentage_j} * (\mathrm{maxWTP_j} + \left(2 * \mathrm{harvest.costs} * \mathrm{volume_{ji}}\right) + (\mathrm{transportation.cost} * \mathrm{yield_{silage}} * \mathrm{volume_{ji}} * \mathrm{distance_{ji}})} \quad \text{(A11)}$$

In equation A12, volume_{ji} is the maximum possible volume (ton DM) that can be traded between buyer j and seller i, $\mathrm{distance}_{ji}$ is the eucleadian distance (km) between buyer j and seller i. The transportation costs between agent j and agent i are calculated as:

$$\mathrm{transportation.cost_{ji}} = P_{agr.contractor} * \frac{1}{-0.0241 * distance_{ji}{}^2 + 1.2256 * distance_{ji} + 27.581} * \frac{1}{density.silage * volume.cart} \quad \text{(A12)}$$

With $P_{agr.contractor}$ the price of the agricultural contractor fixed at 70 €/hour, denistiy.silage the density of freshly chopped silage maize, which equals 0.12 ton DM/m³ and volume.cart the volume of the transportation cart, which we assumed 40 m³.

Furthermore, the agents calculate the value of the trust relationship they have built up over the years, using the equation proposed by Klos and Nooteboom (Klos & Nooteboom 2001):

$$trust_{ji} = b_{ij} + ((1 - b_{ij}) * \left(1 - \frac{1}{fz_{ij} + 1 - f}\right)) \quad \text{(A13)}$$

in which b_{ij} is the basic level of trust between agent i and j, parameter f is the trust factor, which determines how fast trust between two agents grows and z_{ij} is the number of times the agent j has purchased silage maize from agent i.

Based on the relative additional cost and the calculated value of trust, the agent can than calculate the score he attaches to the seller, using following equation:

$$score_{ji} = relative.additional.cost_{ji}{}^{\alpha_j} * trust^{1-\alpha_j} \quad \text{(A14)}$$

In equation A11, the dimensionless parameter α_j is the weight buyer j attaches to making profit, compared to staying loyal.

Finally, the agents make an offer ($offer_{ji}$) to the sellers, equal to the maxWTP minus the transportation costs. How many offers they make depends on the size of their own deficit ($silage.maize.deficit_j$), compared to the overall deficit (total.silage.maize.deficit).

$$Number.of.bids_j = \frac{silage.maize.deficit_j}{total.silage.maize.defit} \tag{A15}$$

The sellers that receive these offers calculate the relative additional revenue they can make by selling their surplus as silage maize to another agent j, compared to selling it on the grain market:

$$Relative.additional.revenue_{ij} = \frac{offer_{ji} * volume_{ji}}{P_{grain} * volume_{ji} * yield_{grain}} \tag{A16}$$

Similarly to the buyers, they calculate a score which they assign to each of the buyers of whom they received an offer:

$$score_{ij} = relative.additional.revenue_{ij}{}^{\alpha_i} * trust_{ij}{}^{1-\alpha_j} \tag{A17}$$

In this equation, $trust_{ij}$ is calculated using equation A10. Finally, the agents with a silage maize surplus sell their surplus to the byers with the highest score. However, if the offer is less than their minimum willingness to accept (minWTA, expressed in €/ha) (equation A10), they sell their surplus on the grain market.

The auction module is repeated 5 times every run. Finally, the simulations end after 16 runs, representing a period of 16 years.

Annex B: ODD-protocol of the agent-based model presented in chapter 3

B.1. Overview

B.1.1. Purpose

The agent-based model presented in this document was developed to investigate the potential of a corn stover value chain for large-scale processing in areas with smaller scale agriculture compared to small-scale decentralized processing. More specifically, we were interested whether competition between large-scale centralized processing and small-scale decentralized processing enhance the development of a corn stover value chain in such regions? The agent-based model was developed in R (R Core Team 2015)

This document details the ABM we developed using the ODD (Overview, Design and Details) protocol (Grimm et al. 2006; Grimm et al. 2010). The ABM simulates the behaviour of four main agent types: farmers, custom harvesters, biogas plant managers and one manager of a cellulosic sugar production plant. The simulations were done for three scenarios, allowing us to investigate the effect of competition on the development of a corn stover value chain in Flanders.

It should be noted that the goal of the model is not to simulate reality and yield specific numbers, but rather to gain more insights into the influence of competition on the behavior of the different stakeholders in the corn stover value chain and the corn stover prices.

B.1.2. State variables and scales

B.1.2.1. Structure of the model system

The goal of the model is to simulate the development of a corn stover value chain under different competition scenarios. Therefore, we have developed a basic model structure and adopted it according to the competition scenario simulated. Figure B.1 shows a general schematic overview of the model.

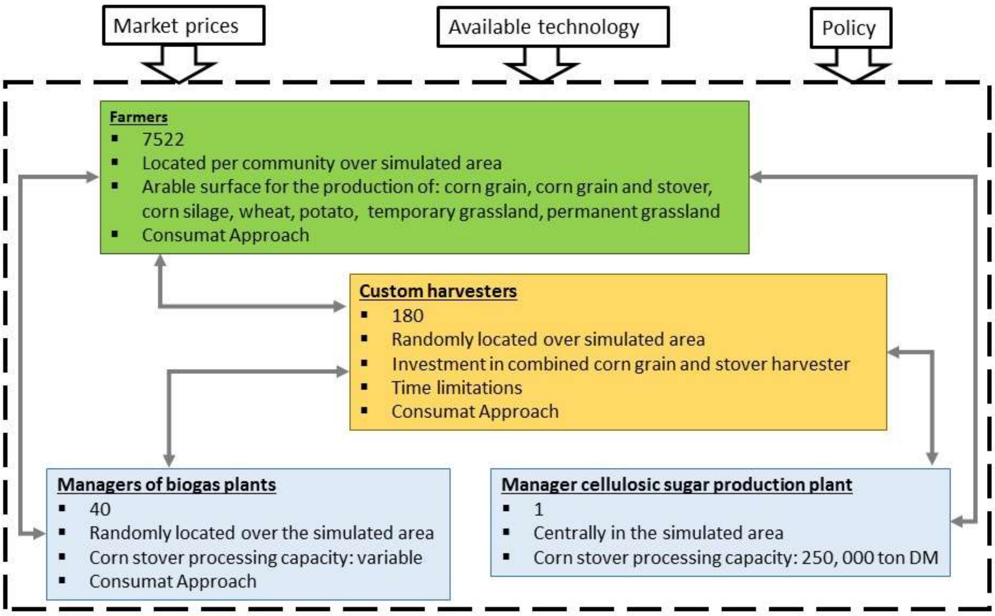


Figure B.1 Schematic representation of the ABM, showing the four agent types included in the model and their main features. The grey arrows represent the interactions between the agents. The dashed rectangle shows the model boundary and external factors.

B.1.2.2. Agents

The model includes four main agent types and two additional agent types. The four main agent types are farmers, custom harvesters, biogas plant managers and one manager of a cellulosic sugar production plant. Grain traders, or traders of the five other crops, suppliers of manure, silage maize and OBA’s, as well as buyers of the cellulosic sugar and the lignin byproduct are not explicitly included in the model. Table B.1. shows an overview of the main agent types and their attributes.

Table B.1 Overview of the modelled agent types and their attributes

Agent type	Attribute	Value/Range	Distribution	Mean (standard deviation)	Reference
Farmers	Total number	7522			(FOD Economie-Algemene Directie Statistiek 2014)
	Location	According to municipality			(FOD Economie-Algemene Directie Statistiek 2014)
	Aspiration level		Normal	0.5(0.17)	(van Duinen et al. 2016)
	Uncertainty tolerance		Normal	0.5 (0.17)	(van Duinen et al. 2016)
	Discounting factor	0.2 – 0.8	Uniform		(van Duinen et al. 2016)
	Network radius close network (km)	10			/

Transportation cost corn stover (€/ton DM/km)	0.2	Derived from series of semi-structured interviews
Arable land surface (hectare)		
Corn grain	7.63	(FOD Economie-Algemene Directie Statistiek 2014)
Corn for silage	2.88	(FOD Economie-Algemene Directie Statistiek 2014)
Potato	2.96	(FOD Economie-Algemene Directie Statistiek 2014)
Wheat	4.47	(FOD Economie-Algemene Directie Statistiek 2014)
Permanent grassland	4.84	(FOD Economie-Algemene Directie Statistiek 2014)
Temporary grassland	1.64	(FOD Economie-Algemene Directie Statistiek 2014)
Yield (ton DM / hectare) (depending on agro-ecological zone)		
Corn grain	10.57 – 12.30	(FOD Economie-Algemene Directie Statistiek 2016)
Corn grain when harvest stover	9.72 – 11.32	(FOD Economie-Algemene Directie Statistiek 2016)
Corn stover	7.78 – 9.06	(FOD Economie-Algemene Directie Statistiek 2016)
Corn for silage	14.52 – 16.57	(FOD Economie-Algemene Directie Statistiek 2016)
Potato	44.86 – 50.84	(FOD Economie-Algemene Directie Statistiek 2016)
Wheat	7.82 – 10.07	(FOD Economie-Algemene Directie Statistiek 2016)

	Production costs (€ / hectare)				
	Corn grain	953.3			(LCV 2012)
	Corn for silage	1476.7			(LCV 2012)
	Potato	3172			(De Regt & Deuninck 2010)
	Wheat	1600			(Boeren Op Een Kruispunt n.d.)
	Permanent grassland	913.7			(LCV 2012)
	Temporary grassland	913.7			(LCV 2012)
Custom harvesters	Total number	180			/
	Location		Uniform		/
	Aspiration level		Normal	0.5 (0.17)	(van Duinen et al. 2016)
	Uncertainty tolerance		Normal	0.5 (0.17)	(van Duinen et al. 2016)
	Discounting factor	0.2 – 0.8	Uniform		(van Duinen et al. 2016)
	Discount rate	0.07			(Bral 2014)
	Network probability	0.3			
	Maximum harvest surface grain (hectares/year)	400			Derived from series of semi-structured interviews
	Maximum harvest surface corn + corn stover (hectares / year)	300			Derived from series of semi-structured interviews
	Harvest price grain (€/hectare)	175			Derived from series of semi-structured interviews
	Price single-pass harvester (€)	430,920			(Vadas & Digman 2013)
	Depreciation time (years)	12			(Vadas & Digman 2013)
	Interest rate (%)	2.1			Derived from series of semi-structured interviews
	Insurance cost (€/year)	8618.4			Derived from series of semi-structured interviews
	Repair costs (€/ha)	22.31			Derived from series of semi-structured interviews
	Oils cost (€/year)	3000			Derived from series of semi-structured interviews
	Labour costs (€/hour)	25			Derived from series of semi-structured interviews
	Fuel use (liter/hectare)	17.8			(Vadas & Digman 2013)
	Fuel cost (€/liter)	0.66			Derived from series of semi-

				structured interviews
	Transportation cost stover (€/ton DM/ km)	0.2		Derived from series of semi-structured interviews
	Collection efficiency	0.8		(Vadas & Digman 2013)
Biogas plant managers	Total number	40		/
	Location		Uniform	/
	Aspiration level	0 – 1	Uniform	/
	Uncertainty tolerance	0 – 1	Uniform	/
	Discounting factor	0.2 – 0.8		/
	Network probability	0.3		/
	Maximum processing capacity (ton / year)	44051		(Willeghems & Buysse 2016)
	Initial silage maize processing (ton / year)	6607		(Willeghems & Buysse 2016)
	Initial manure processing (ton / year)	11013		(Willeghems & Buysse 2016)
	Initial organic waste processing (ton / year)	26431		(Willeghems & Buysse 2016)
	Price manure (€/ton)	-17		(Willeghems & Buysse 2016)
	Price organic waste (€/ton)	10		(Willeghems & Buysse 2016)
	Methane yield silage maize (m³ CH_4/ton)	95		(De Dobbelaere et al. n.d.)
	Methane yield corn stover (m³ CH_4/ton)	85		(De Dobbelaere et al. n.d.)
	Methane yield manure (m³ CH_4/ton)	17.5		(Willeghems & Buysse 2016)
	Methane yield municipal waste (m³ CH_4/ton)	85		(Willeghems & Buysse 2016)
	Share electricity CHP	0.35		(Willeghems & Buysse 2016)
	Share heat CHP	0.50		(Willeghems & Buysse 2016)
	Price subsidies electricity production (€/MWhe)	93		(Willeghems & Buysse 2016)
	Price subsidies heat production (€/MWhth)	31		(Willeghems & Buysse 2016)
	Price electricity (€/MWhe)	45		(Willeghems & Buysse 2016)
	Price electricity avoided (€/MWhe)	140		(Willeghems & Buysse 2016)

	Price heat avoided (€/MWhth)	45	(Willeghems & Buysse 2016)
	Own electricity consumption	0.2	(Willeghems & Buysse 2016)
	Own heat consumption	0.35	(Willeghems & Buysse 2016)
CSPP managers	Total number	1	/
	Location	Central in modelled environment	
	Maximum operating capacity (ton DM/year)	250 000	(Duffy & Marchand 2013)
	Production cellulosic sugar (ton DM/ ton corn stover)	0.46	(Duffy & Marchand 2013)
	Production of lignin byproduct (ton DM/ ton corn stover)	0.36	(Duffy & Marchand 2013)
	Price cellulosic sugar (€/ton DM)	362.88	(Duffy & Marchand 2013)
	Price lignin byproduct	36.29	(Duffy & Marchand 2013)
	Maximum willingness to pay corn stover (€/ton DM)	117.27	(Duffy & Marchand 2013)
	Fixed costs (€/year)	4 109 616	(Duffy & Marchand 2013)
	Operating costs (€/ton DM)	362.29	(Duffy & Marchand 2013)

As we investigated the effect of competition on the development of the corn stover value chain in Flanders, the agents are located over the surface of Flanders. Farmers are located in the center of their respective municipality, which could be derived from (FOD Economie-Algemene Directie Statistiek 2014). The custom harvesters and the biogas plant managers are randomly distributed over the area. Finally, the cellulosic sugar production plant is located in the geographical center of Flanders. The figure below shows the configuration of one stochastic realization.

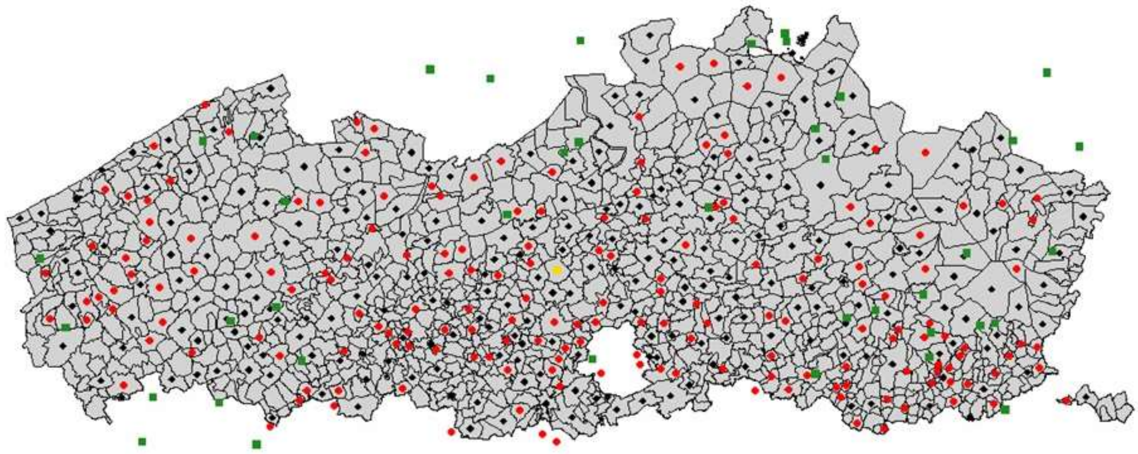


Figure B.2 Representation of the modelled area in one stochastic configuration before the start of a simulation. The black diamonds represent farmers, the red dots, custom harvesters, the green squares biogas plants and the yellow square the cellulosic sugar production plant.

The model proceeds in annual time steps over a period of 12 years, corresponding to the depreciation time of a combined corn grain and stover harvester. There is no hierarchical difference between the farmers, custom harvesters, biogas plant managers and the manager of the cellulosic sugar production plant, meaning that these agents operate at the same level.

Finally, several auxiliary variables are included in the model, available to all agents in the model:

- Crop prices for corn grain, corn silage, potato and wheat in €/ton DM for the years 2003 – 2014 (Wageningen UR 2014)
- Values for temporary grassland and permanent grassland are expressed in €/ha for the years 2003 – 2014 (Wageningen UR Livestock Research 2014).

B.1.2.3. Markets

The model simulates the development of the corn stover value chain under different competition scenarios. Hence, the trade of corn stover is explicitly modelled and can be influenced by the agents. The trade of corn stover is simulated as a corn stover spot market. In this market, farmers interested in selling stover negotiate individually with the manager of the cellulosic sugar production plants or the biogas plant managers. Farmers are responsible for the harvesting and transportation of the stover to the processing plants. Therefore, they need to find a custom harvester that is willing to invest or has already invested in a single-pass harvester. As a result, farmers also bear the costs of these activities. They pay the CHs fixed price of 161€/ha.

Besides growing corn for the harvest of corn grain and stover, farmers have the option to grow six other crops: corn for grain harvest only, corn silage, wheat, potato, temporary grassland

and permanent grassland. The reason for the selection of these crops was that they represented 95% of the total arable surface cultivated by farmers that grown corn grain in 2010 (FOD Economie-Algemene Directie Statistiek 2014). The markets of these crops are exogenously determined, meaning that the crop prices can influence the farmers' behaviour. On the other hand, the farmers' decisions have no direct influence on the market prices for these crops. The market prices were derived from (Wageningen UR 2014; Wageningen UR Livestock Research 2014).

Furthermore, the agents' profits are influenced by fuel and labour prices, next to cellulosic and lignin by-product prices. However, the agents in our model cannot influence these markets (Figure B.1).

B.1.3. Process overview and scheduling

The ABM developed was applied to four scenarios in which biogas plant managers and the manager of the cellulosic sugar production plant are active in the market depending on the scenario. Figure B.3 shows a general overview of the main model procedures.

B.1.3.1. Setup

At the start of each simulation, a setup is executed which initializes the simulation environment. The auxiliary variables (globals), farmers, custom harvesters, biogas plant managers and the manager of the cellulosic sugar production plant are always initialised at the start of the simulations.

Furthermore, each farmer in the model is connected to other farmers by means of a network. A farmer's close network contains all farmers within a radius of 10 kilometres from the farmer (Table B.1). A farmers' broad network contains all farmers within the same agro-ecological region (FAO 2002). Custom harvesters are connected through an Erdös-Renyi network (Peres 2014), in which each custom harvester has a probability of 0.3 to be connected to another custom harvester. Each of these connections is randomly assigned a value, which represents the strength of the connection. Connections with a value equal or larger than 0.5 represent a custom harvester's close network, connections with a value between 0 and 0.5 represent a custom harvester's broad network. A similar network is established amongst the biogas plant managers. Finally, upon initialisation, each farmer is assigned to a custom harvester, meaning that that particular custom harvester is responsible for harvesting the farmer's corn grain. The initial contract between a farmer and a CH is based on minimum distance and the available capacity of the CH.

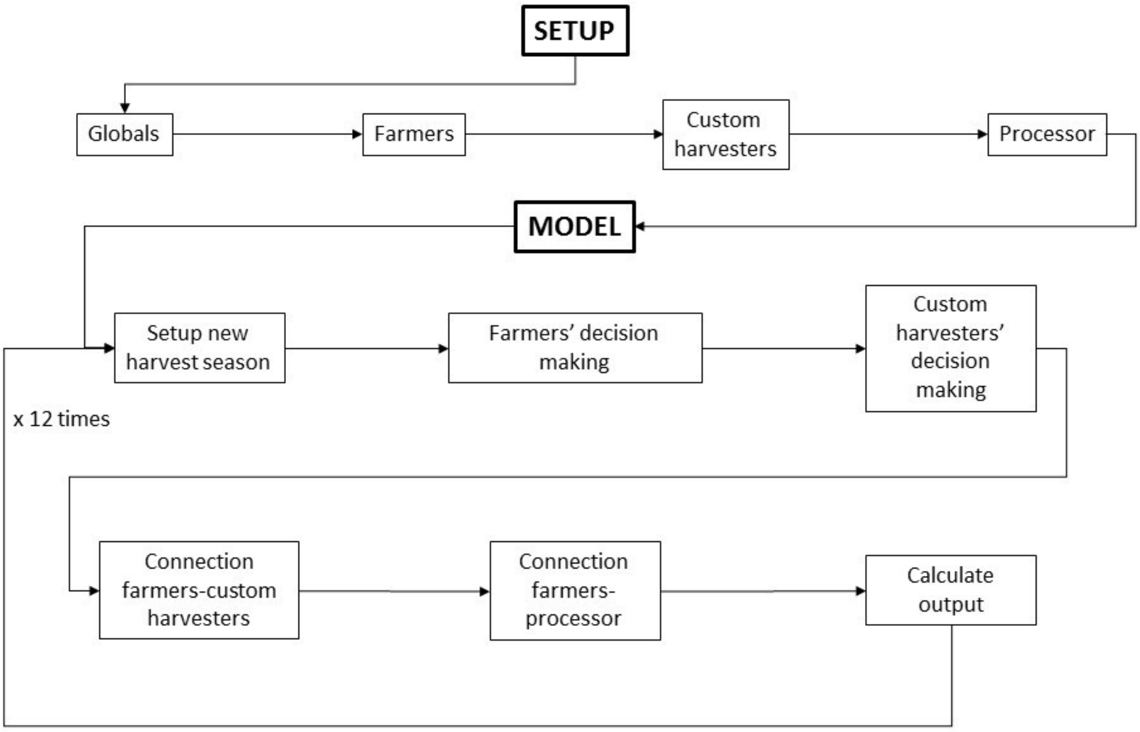


Figure B.3 Schematic overview of the main model procedures

B.1.3.2.Setup new harvest season

After the setup, the actual simulations are started. In total, the model is repeated 12 times, simulating a total period of 12 years. Each year, a new harvest season is initialized. This means that some agents' parameters are reset to their initial values. These values are presented in Table B.2.

Table B.2 Parameters reset after each simulated year

Parameter	Value
Farmers	
Highest bid for stover (€/ha)	0
Processor contract	0
Stover supply (ton DM)	0
Interest in selling stover	False
Total revenue (€)	0
Custom harvesters	
Interest in investing in combined corn grain and stover harvester	False
NPV	0
Number of hectares to harvest stover under contract	0
Processor contract	0
Number of hectares purchased (ha)	0
Biogas plant managers and manager of cellulosic sugar production plant	
Number of custom harvesters under contract	0
Stover price bid (€/ha)	0
Volume of stover purchased (ton DM)	0
Number of hectares of stover purchased (ha)	0
Total stover cost (€)	0
Average stover cost (€/ton DM)	0
Total expenses (€)	0

B.1.3.3. Biogas plants', farmers' and custom harvesters' decision making procedure

The farmers' and custom harvesters' decision making procedure is schematically represented in Figure B.4. In this procedure, the two agent types start by calculating their potential gross margin (PGM). A biogas plant manager's gross margin is the maximum gross margin a biogas plant manager can obtain by optimizing the inputs he uses given the input prices. A farmer's potential gross margin is the maximum gross margin per hectare a farmer can obtain by optimizing his cropping plan given the current crop prices. For the custom harvesters, the potential gross margin is calculated as the maximum gross margin they can generate, given the machinery they have.

Next, the agents calculate the actual gross margin (AGM). For the biogas plant managers, this calculation is based on the current input prices and the production costs. For the farmers, this calculation is based on the current crop prices and the production costs for each crop in their cropping plan. For the custom harvesters, the calculation of the AGM is based on the machinery they have and the amount of hectares have under contract to harvest.

Based on the AGM and the PGM, the agents determine their economic satisfaction (ES), which can be regarded as a proxy for the answer to the question: ""Am I happy with the gross margin I generated, given my current assets (e.g. arable land or machinery)?". The ES is calculated as the ratio of an agent's AGM over his PGM. The second variable is uncertainty (U), which is a proxy for the answer to the question: : "How certain am I that the cropping/ machinery investment / input decisions I made were good decisions given the average economic performance of the other agents?"

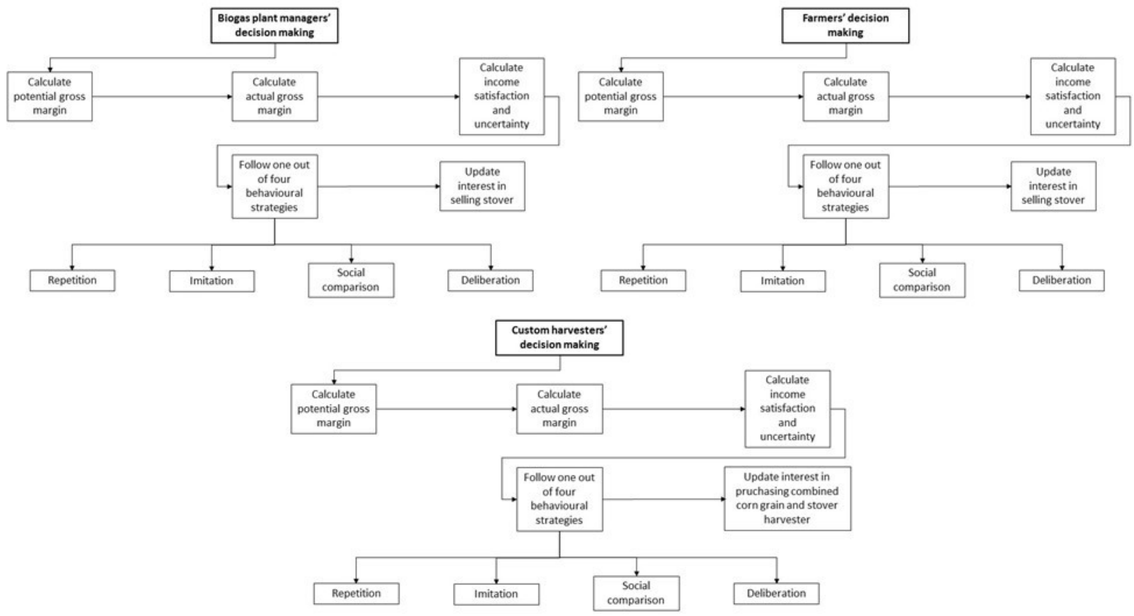


Figure B.4 Schematic overview of the farmers', custom harvesters', and biogas plant managers decision making procedures.

The combination of the ES and the U lead to four different behavioural rules that can be followed by the biogas plant managers, the farmers and the custom harvesters (Figure B.5. and Figure B.6.). These behavioural rules are derived from the "Consumat meta-model" as described by (Jager 2000) and the related model developed by (van Duinen et al. 2016).

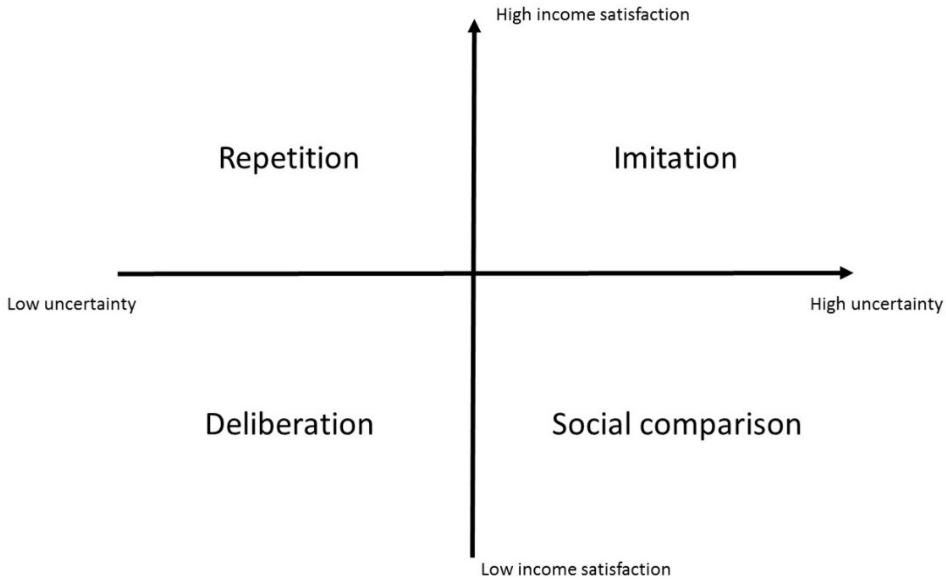


Figure B.5 Four behavioural rules applied by the biogas plant managers, the farmers and the custom harvesters derived from the Consumat meta-model.

The first behavioural rule is **repetition**, applied by agents that are economically satisfied and certain about the decisions they make. Therefore, they are not inclined to make any changes to their behaviour. For the farmers, this means that they keep their current cropping plan. For the custom harvesters, this means that they do not consider the option of investing in a new single-pass harvester. For the biogas plant managers, it means that they will keep their current input plan.

The second behavioural rule is **imitation**, applied by agents that are economically satisfied, but uncertain that their decisions are the best ones. These agents will scan the behaviour of the other agents, but only in their close network and imitate the behaviour of the best performing ones. Imitating farmers will copy the cropping plan of the farmer with the highest AGM in their close network. Imitating custom harvesters will consider purchasing a single-pass harvester if more than half of the CHs in their close network has already made the investment. Imitating biogas plant managers will copy the input plan of the biogas plant manager with the highest AGM in their close network (Figure B.6)

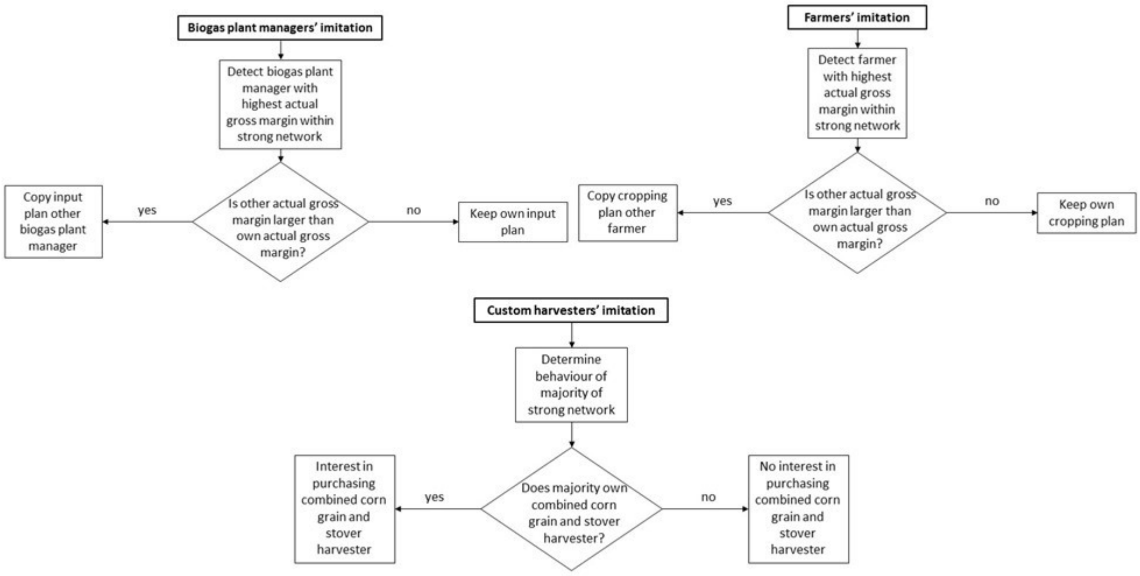


Figure B.6 Schematic overview of the behavioural rule "Imitation" applied by the biogas plant managers, farmers and custom harvesters

The third behaviour is **social comparison**, applied by economically unsatisfied agents uncertain about their decisions. These agents will look at their broad network instead of their close network, in order to improve their situation. Farmers will copy the cropping plan of the farmer with the highest AHM in their broad network. Custom harvesters will consider purchasing a single-pass harvester if more than half of the custom harvesters in their broad network made the investment before. Biogas plant managers will copy the input plan of the biogas plant manager with the highest AGM in their broad network (Figure B.7).

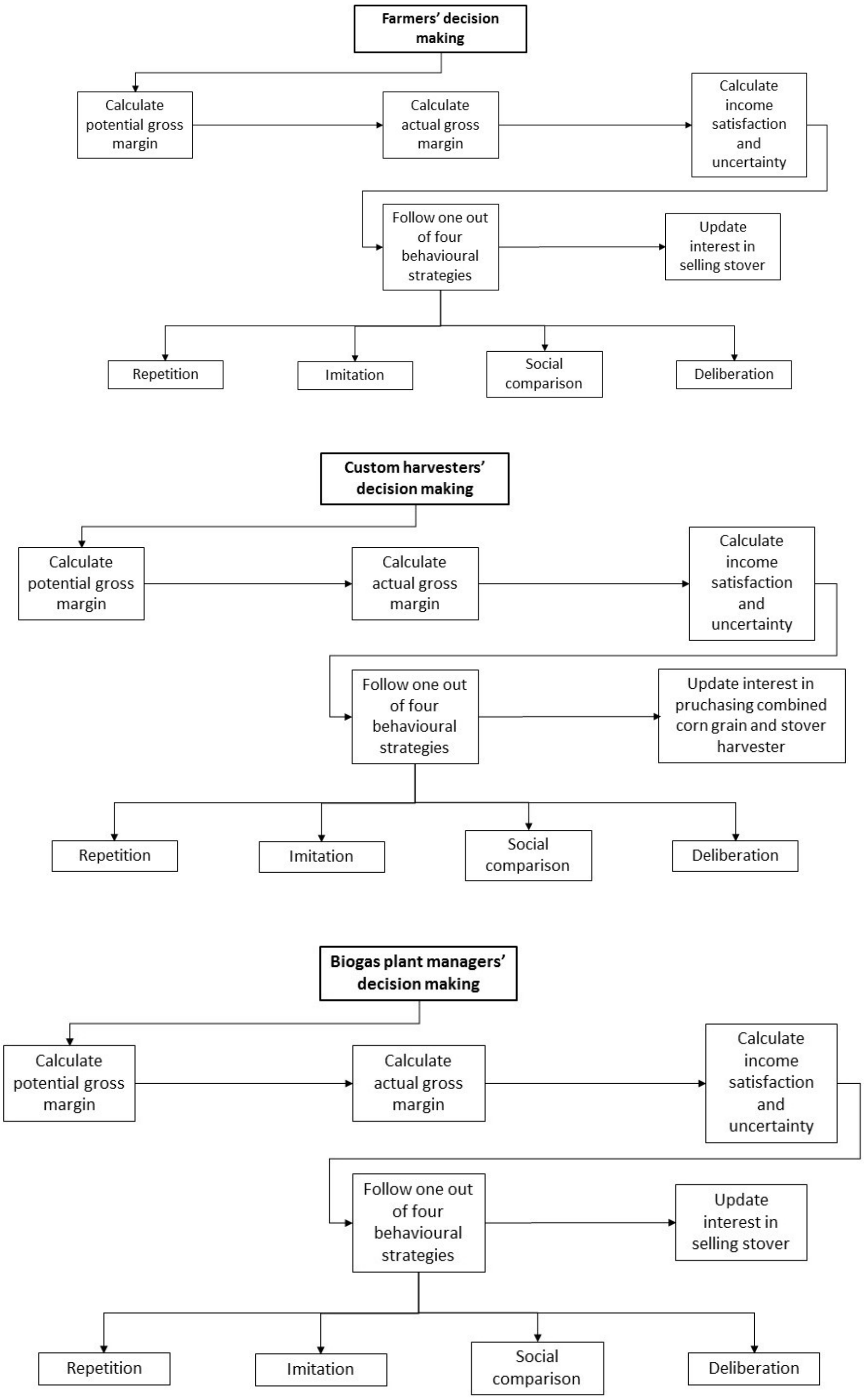


Figure B.7 Schematic overview of the behavioural rule "Social comparison" applied by the biogas plant managers, farmers and custom harvesters

The final behavioural rule is **deliberation**, which is the most economic rational behaviour and is applied by agents, certain about their decisions, but with a low economic satisfaction. Deliberating farmers will maximize their gross margin by optimizing their cropping plan given the current crop prices. Deliberating custom harvesters will consider purchasing a single-pass harvester if the net present value (NPV) of their investment is positive. It must be noted that custom harvesters will only invest in a single-pass harvester if they have a contract to harvest that year. Deliberating biogas plant managers will maximize their gross margin by optimizing their input plan given the current input prices (Figure B.8).

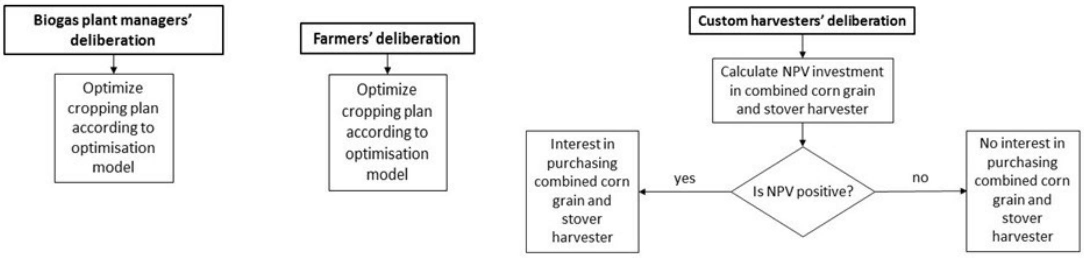


Figure B.8 Schematic overview of the behavioural rule "Deliberation" applied by the biogas plant managers, farmers and custom harvesters

B.1.3.4. Connection farmers – custom harvesters procedure

In this procedure, farmers who want to harvest their stover seek for the closest custom harvester that owns a single-pass harvester or is willing to invest in one. In making the requests, priority is given to custom harvesters that already own a single-pass harvester. The custom harvester accepts the requests until he reached the maximum amount of hectares he can harvest with the harvester (300 hectares per year). If the custom harvester cannot accept any more requests, the farmer will look for the nearest custom harvester who hasn't reached his maximum capacity. Every custom harvester that is interested in buying a single-pass harvester will make the investment if he has a contract to harvest. Finally, farmers who have found a custom harvester who has the necessary harvesting equipment will also switch to this custom harvester for the harvesting of corn grains from fields from which they do not want to harvest the stover. Farmers who were willing to harvest the stover, but were not able to close a contract with a custom harvester will grow corn for the harvest of the grains only on the surfaces originally destined for corn grain and stover harvest.

B.1.3.5.Connection farmers – processors procedure

In this procedure, the farmers sell the corn directly to the processor with the highest bid. In a first step, farmers calculate the minimum willingness to accept for the stover (minWTA). In this calculation, they take into account a reduced corn grain yield in corn varieties of which the stover can be harvested. Furthermore, they take into account the additional harvest costs and the transportation costs to the biogas plants or to the cellulosic sugar production plant. The biogas plant managers calculate their maximum willingness to pay (maxWTP) based on the corn silage prices. The manager of the cellulosic sugar production plant is assigned a maxWTP at the start of the simulations. However, as the processors are not willing to bid their maxWTP, this value is adjusted using a compromising factor (explained in more detail below). Next, the processors send out this price bid to all farmers that are willing and able to sell stover. The farmers accept the largest bid which is greater than their minWTA.

B.1.3.6. Calculate output

Every simulated year, the model output is calculated and stored in a matrix. The output variables are:

- The simulation cycle
- Number of simulated years
- Number of farmers with repeating behaviour
- Number of farmers with deliberating behaviour
- Number of farmers with imitating behaviour
- Number of farmers with social comparative behaviour
- Total hectares of corn grown for corn grain only
- Total hectares of corn grown for corn grain and corn stover
- Total hectares of corn grown for silage
- Total hectares of potatoes
- Total hectares of wheat
- Total hectares of permanent grassland
- Total hectares of temporary grassland
- Number of farmers willing to sell corn stover
- Number of farmers actually selling corn stover
- Average corn stover supply per farmer
- Number of custom harvesters with repeating behaviour
- Number of custom harvesters with deliberating behaviour
- Number of custom harvesters with imitating behaviour
- Number of custom harvesters with social comparative behaviour
- Number of custom harvesters with a single-pass harvester
- Volume of corn stover purchased by the manager of the cellulosic sugar production plant
- Number of biogas plants purchasing corn stover
- Average volume of corn stover purchased by the biogas plants
- Total corn stover volume purchased by the biogas plants
- Average corn stover price paid by the manager of the cellulosic sugar production plant
- Average corn stover price paid by the biogas plant managers
- Average corn stover farm gate price received by the farmers
- Total revenue made by the manager of the cellulosic sugar production plant

- Net income of the manager of the cellulosic sugar production plant

Additionally, for all individual agents, the different parameters and variables are saved in separate csv-files for each agent type. This allowed us to double check the results.

B.2. Design concepts

B.2.1. Basic principles

The goal of the ABM is to be able to investigate the development of a corn stover value chain under different competition scenarios. Different information sources contributed to the design of the ABM. Firstly, in order to gain a first general insight into the opportunities and challenges related to the establishment of a corn stover value chain, we conducted semi-structures interviews with experts and possible stakeholders, including farmers and custom harvesters. Next, a literature study was conducted on the techno-economic aspects of corn stover harvest, logistics and processing (Petrolia 2008; Hess et al. 2009; Thompson & Tyner 2014; Gan & Smith 2011; Sokhansanj et al. 2002; Sokhansanj et al. 2010; Babcock et al. 2011; Aden & Foust 2009). Finally, in order to conceptualize the decision behaviour of the biogas plant managers, the farmers and the custom harvesters, the Consumat approach was included in the model (Jager 2000; van Duinen et al. 2016). After a preliminary version of the model was developed, a workshop was organized for different experts of corn stover harvest, logistics and processing. In this workshop, the model and the preliminary results were presented to the 9 participants. Feedback given by the participants was taken into account to build the final version of the model.

B.2.2. Emergence

The model allowed us to observe the development of a corn stover value chain and its characteristics under different competition scenarios. Competition has an influence on the corn stover prices, and on the adoption rate of the farmers.

B.2.3. Adaptation

Adaptation is included at different points in the ABM. Firstly, with regard to the behavioural rules for making decisions, we applied the Consumat Approach, based on (Jager 2000; van Duinen et al. 2016) for the biogas plant managers, the farmers and the custom harvesters. The behavioural rules lead to biogas plant managers adjusting their input plan, farmers adjusting their cropping plan and the option for custom harvesters to purchase a single-pass harvester. In this sense, the adaptive trait is a way agents seek to increase their success, namely their actual gross margin. The way the agents adapt their behaviour is explained in more detail below.

Also, an adaptive trait is included regarding the corn stover purchasing behaviour. When a processor wants to purchase stover he is not willing to make a price bid equal to his maxWTP, but prefers to pay a lower price. Therefore, the sale and purchase of stover is modelled as a sealed bid auction repeated multiple times in order to simulate a negotiation process. In total the negotiation procedure is repeated 6 times, simulating the 6 months between the harvest of the maize crop and the planting of new crops. In each negotiation round, the buying agent adjusts his maximum bid by multiplying it with a compromising factor, in analogy with Shastri *et al.* (2011) (Shastri et al. 2011). This Cr-factor is calculated using Equation B1 and Equation B2.

$$Cr = v^3 \tag{B1}$$

$$v = max[\frac{n}{N}, \frac{t}{T}] \tag{B2}$$

with n the amount of corn stover the agent was already able to purchase, N the agent's total stover demand (N), t the number of auction rounds before the season is over and T the total number of bidding rounds.

B.2.4. Objectives

As explained before, agents adjust their behaviour to increase their actual gross margin compared to their potential gross margin. For the farmers, the potential gross margin (PGM) is calculated as the maximum gross margin per hectare a farmer can obtain, by optimizing his cropping plan given the current crop prices (Equations B3 – B8).

$$Maximise: \sum_{c=1}^{n}((Y_{i,c} * P_{c,t}) - C_c) * S_{i,c,t} \tag{B3}$$

subject to (s.t.)

$$\sum_{c=1}^{n} S_{i,c,t} \leq ST_i \tag{B4}$$

$$S_{i,c,t} \geq 0 \tag{B5}$$

$$S_{i,perm\ grass,t} \geq 0.05 * ST_i \tag{B6}$$

$$S_{i,c,t} \leq 0.75 * ST_i \tag{B7}$$

$$S_{i,potato,t} \leq \frac{1}{3} * ST_i \tag{B8}$$

In Equation B3, $Y_{i,c}$ is the yield of crop c produced by farmer i (ton DM/ha), $P_{c,t}$ is the price for crop c in year t (€/ton DM), C_c the production costs of crop c (€/ha), $S_{i,c,t}$ the surface of crop c grown by farmer i in year t (ha). Hence, one maximises the gross margin a farmer can obtain. This maximisation is done under a number of conditions (Equation B4 – B8). The first condition (Equation B4) ensures that the sum of the arable land devoted by farmer i to each crop is not larger than the total arable surface available to farmer i (ST_i in ha). The second condition (Equation B5) ensures farmers cannot devote a negative arable surface to a certain crop. The third condition (Equation B6) ensures that at least 5% of the total arable land cultivated by farmer i is devoted the cultivation of permanent grassland ($S_{i,perm\ grass,\ t}$ in ha). The fourth condition (Equation B7) ensures that one crop does not take more than 75% of the total arable land cultivated by farmer i. Finally, the last condition (Equation B8) ensures that the obliged rotation for potato, which states that potatoes can only be grown on the same land every three years, is fulfilled. The actual gross margin is calculated as presented in Equation B9.

$$AGM_{i,t} = Y_{i,t} = \frac{\sum_{c=1}^{n}((P_{c,t} * Y_{i,c} * S_{i,c,t}) - (C_c * S_{i,c,t}))}{ST_i} \quad (B9)$$

For the custom harvesters, the actual gross margin and PGM is calculated as shown in Equation B10.

$$ES_{i,t} = \frac{AGM_{i,t}}{PGM_{i,t}} = \frac{(S_{i,Grain,t} * (P_{Grain} - C_{Grain})) + (S_{i,Stover,t} * (P_{Stover} - C_{Stover}))}{(S_{maxGrain} * (P_{Grain} - C_{Grain})) + (S_{maxStover} * (P_{Stover} - C_{Stover}))} \quad (B10)$$

In Equation B10, $S_{i,Grain}$ is the actual harvested surface of corn grain by custom harvester i (ha), $S_{i,Stover}$ is the actual harvested surface of corn stover by custom harvester i (ha), $S_{maxGrain}$ is the maximum surface of corn grain that can harvested with one combine (ha), $S_{maxStover}$ is the maximum surface of corn grain and stover that can harvested with the single pass harvester (ha), P_{Grain} is the harvest price of corn grain (€/ha), P_{Stover} is the harvest price of corn grain and stover (€/ha), C_{Grain} are the variable costs of harvesting corn grain and C_{Stover} are the variable costs of harvesting corn grain and stover.

For the biogas plant managers, the potential gross margin (PGM) is calculated as the maximum gross margin he can obtain, by optimizing his input plan given the current input prices (Equations B11 – B14).

$$\text{Maximize } \left(\sum_i Q_{i,t} Y_i * \varepsilon\right) * \Big[0.35 * \Big((1 - \varphi_{elec}) * \pi_{elec} + \sigma_{GEC} + \varphi_{elec} * \pi_{elec,avoid}\Big) + 0.5 * \Big((1 - \varphi_{heat}) * \pi_{heat} + \sigma_{GHC} + \varphi_{heat} * \pi_{heat,avoid}\Big)\Big] - (115{,}846 + (110 * \sum_{i,t} Q_{i,t}) - 691.794 - (Q_{i,t} * P_{i,t})) \quad (B11)$$

s.t.

$$\sum_{i=1}^{n} Q_{i,t} \leq QT \quad (B12)$$

$$Q_{i,t} \geq 0 \quad (B13)$$

$$Q_{corn\ silage,t} + Q_{corn\ stover,t} \geq 0.15 * QT \quad (B14)$$

In Equation B11 $Q_{i,t}$ (ton) is the volume of input i at time t used in the biogas plant, Y_i (m^3 CH_4 / ton,) the methane yield of product i, ε (MWh/m^3) is a conversion factor, ϕ_{elec} and ϕ_{heat} the relative amount of own electricity and heat consumption respectively, π_{elec} (€/MWhe) and π_{heat} (€/MWhth) the revenue from sale of generated electricity and heat respectively, $\pi_{elec,avoid}$ (€/MWhe) and $\pi_{heat,avoid}$ (€/MWhth) the expenses avoided due to own consumption of electricity and heat respectively, σ_{GEC} (€/ MWhe) and σ_{heat} (€/MWhth) subsidies in the form of green electricity certificates and green heat certificates respectively and $P_{i,t}$ the price of input i at time t. This maximisation is done under a number of conditions (Equation B12 – B14). The first condition (Equation B12) ensures that the sum of volumes of each input i is not larger than the maximum capacity of the biogas plant (QT in ton). The second condition (Equation B13) ensures biogas plants cannot devote a negative volume to a certain input. The third condition (Equation B14) ensures that at least 15% of the total inputs is either silage maize or corn stover (Willeghems & Buysse 2016).

B.2.5. Learning

Learning is not explicitly included in the model

B.2.6. Prediction

Prediction is not explicitly included in the model

B.2.7. Sensing

In the model, the farmers are aware of the crop prices and the cultivation costs. Biogas plant managers are aware of the prices of the inputs. Moreover, farmers, custom harvesters and biogas plant managers aware of the average actual gross margin of the other agents of the same agent type, which they use to calculate their uncertainty value.

Furthermore, at the start of the simulations, each farmer in the model is connected to other farmers by means of a network. A farmer's close network contains all farmers within a radius of 10 kilometres from the farmer (Table B.1). A farmer's broad network contains all farmers within the same agro-ecological region. Custom harvesters and biogas plant managers are connected through an Erdös-Renyi network (Peres 2014), in which each custom harvester or each biogas plant manager has a probability of 0.3 to be connected to another custom harvester or biogas plant manager respectively. The agents are aware of the decisions of the other agents in their network. For the farmers, this means that they are aware of the cropping plan of the other farmers in their network. The custom harvesters know which other custom harvesters in their network own a single-pass harvesters. Finally, the biogas plant managers are aware of the input plan of the other biogas plant managers in their network. This knowledge is used by the farmers, the custom harvesters and the biogas plant managers to make their decisions in the imitation and social comparison decision rule.

B.2.8. Interaction

Direct interaction between agents takes place when corn stover is traded and agents involved negotiate on the corn stover price (section 2.3). Furthermore, there is direct interaction between farmers and custom harvesters when corn stover is harvested.

Indirect interaction amongst farmers, amongst custom harvesters and amongst biogas plant managers takes place when these agents compare their own actual gross margin to the average actual gross margin of their respective agent type.

Communication between the agents is not explicitly modelled.

B.2.9.Stochasticity

There are several state variables that are randomly initialized:

- Farmers:
    - Farmers are assigned a random aspiration level value with a mean of 0.5 and a standard deviation of 0.17
    - Farmers are assigned a random uncertainty tolerance value with a mean value of 0.9 and a standard deviation of 0.17
    - Farmers are assigned a random discounting factor ranging between 0.2 and 0.8.
- Custom harvesters:
    - Custom harvesters are randomly located over the simulated area.
    - Custom harvesters are assigned a random aspiration level value with a mean of 0.5 and a standard deviation of 0.17.
    - Custom harvesters are assigned a random uncertainty tolerance value with a mean of 0.5 and a standard deviation of 0.17.
    - Custom harvesters are assigned a random discounting factor ranging between 0.2 and 0.8.
    - Upon initialisation, an Erdös-Renyi network is created amongst the custom harvesters with a network probability of 0.3.
- Biogas plant managers
    - Biogas plant managers are randomly located over the simulated area.
    - Biogas plant managers are assigned a random aspiration level value with a mean of 0.5 and a standard deviation of 0.17.

- Biogas plant managers are assigned a random uncertainty tolerance value with a mean of 0.5 and a standard deviation of 0.17.
- Biogas plant managers are assigned a random discounting factor ranging between 0.2 and 0.8.
- Upon initialisation, an Erdös-Renyi network is created amongst the biogas plant managers with a network probability of 0.3.

Finally, the order in which the farmers, the custom harvesters and the processors execute the procedures is random.

B.2.10.Collectives

There is no aggregation of agents explicitly included in the model.

B.2.11. Heterogeneity

Farmers, custom harvesters and biogas plant managers are heterogeneous with regard to their state variables (TableB.1) and the decision rules they follow.

B.2.12. Observation

Following output is generated by the model:

- The simulation cycle
- Number of simulated years
- Number of farmers with repeating behaviour
- Number of farmers with deliberating behaviour
- Number of farmers with imitating behaviour
- Number of farmers with social comparative behaviour
- Total hectares of corn grown for corn grain only
- Total hectares of corn grown for corn grain and corn stover
- Total hectares of corn grown for silage
- Total hectares of potatoes
- Total hectares of wheat
- Total hectares of permanent grassland
- Total hectares of temporary grassland
- Number of farmers willing to sell corn stover
- Number of farmers actually selling corn stover
- Average corn stover supply per farmer
- Number of custom harvesters with repeating behaviour
- Number of custom harvesters with deliberating behaviour

- Number of custom harvesters with imitating behaviour
- Number of custom harvesters with social comparative behaviour
- Number of custom harvesters with a single-pass harvester
- Volume of corn stover purchased by the manager of the cellulosic sugar production plant
- Number of biogas plants purchasing corn stover
- Average volume of corn stover purchased by the biogas plants
- Total corn stover volume purchased by the biogas plants
- Average corn stover price paid by the manager of the cellulosic sugar production plant
- Average corn stover price paid by the biogas plant managers
- Average corn stover farm gate price received by the farmers
- Total revenue made by the manager of the cellulosic sugar production plant
- Net income of the manager of the cellulosic sugar production plant

These outcomes were calculated and then stored in a csv-file. The resulting csv-file was then analysed using Excel and R. We included data of all agents for the analysis. Additionally, for all individual agents, the different parameters and variables are saved in separate csv-files for each agent type. This allowed us to double check the results.

B.3. Details

B.3.1. Initialization and input data

A detailed description of the initialization data can be found in Table B.1. Most of these data were based on literature or retrieved from semi-structured interviews. Some of these data (network probability, the number of custom harvesters and the location of the custom harvesters and the biogas plant managers), were arbitrarily chosen as no data were available.

Each simulation round, some state variables are re-initialised. These are presented in Table B.2.

B.3.2. Submodels

In this section, the different submodels of the ABM are discussed, including their equations. We will only discuss the submodels which contain equations.

B.3.2.1. Biogas plant managers', farmers' and custom harvesters' decision making procedure

As explained in before, biogas plant managers', farmers' and custom harvesters' decision making procedure depends on two variables: economic satisfaction and uncertainty. In the model, economic satisfaction is calculated as the ratio of an agent's actual gross margin (AGM) over his potential gross margin (PGM). The potential gross margin for the farmers is calculated as the maximum gross margin per hectare a farmer can obtain, by optimizing his cropping plan given the current crop prices (Equation B15 – B20).

$$Maximise: \sum_{c=1}^{n}((Y_{i,c} * P_{c,t}) - C_c) * S_{i,c,t} \tag{B15}$$

subject to (s.t.)

$$\sum_{c=1}^{n} S_{i,c,t} \leq ST_i \tag{B16}$$

$$S_{i,c,t} \geq 0 \tag{B17}$$

$$S_{i,perm\ grass,t} \geq 0.05 * ST_i \tag{B18}$$

$$S_{i,c,t} \leq 0.75 * ST_i \tag{B19}$$

$$S_{i,potato,t} \leq \frac{1}{3} * ST_i \tag{B20}$$

In Equation B15, $Y_{i,c}$ is the yield of crop c produced by farmer i (ton DM/ha), $P_{c,t}$ is the price for crop c in year t (€/ton DM), C_c the production costs of crop c (€/ha), $S_{i,c,t}$ the surface of crop c grown by farmer i in year t (ha). Hence, one maximises the gross margin a farmer can obtain. This maximisation is done under a number of conditions (Equation B16 – B20). The first condition (Equation B16) ensures that the sum of the arable land devoted by farmer i to each crop is not larger than the total arable surface available to farmer i (ST_i in ha). The second condition (Equation B17) ensures farmers cannot devote a negative arable surface to a certain crop. The third condition (Equation B18) ensures that at least 5% of the total arable land cultivated by farmer i is devoted the cultivation of permanent grassland ($S_{i,perm\ grass,\ t}$ in ha). The fourth condition (Equation B19) ensures that one crop does not take more than 75% of the total arable land cultivated by farmer i. Finally, the last condition (Equation B20) ensures that the obliged rotation for potato, which states that potatoes can only be grown on the same land every three years, is fulfilled. The actual gross margin is calculated as presented in Equation B21.

$$AGM_{i,t} = \frac{\sum_{c=1}^{n}((P_{i,t} * Y_{i,c} * S_{i,c,t}) - (C_c * S_{i,c,t}))}{ST_i} \tag{B21}$$

For the custom harvesters, the AGM is calculated as shown in Equation B22 and the PGM as shown in Equation B23.

$$AGM_{i,t} = (S_{i,Grain} * (P_{Grain} - C_{Grain})) + (S_{i,Stover} * (P_{Stover} - C_{Stover})) \tag{B22}$$

$$PGM_{i,t} = (S_{i,maxGrain} * (P_{Grain} - C_{Grain})) + (S_{i,amaxStover} * (P_{Stover} - C_{Stover})) \tag{B23}$$

In Equation B22 and B23, $S_{i,Grain}$ is the actual harvested surface of corn grain by custom harvester i (ha), $S_{i,Stover}$ is the actual harvested surface of corn stover by custom harvester i (ha), $S_{maxGrain}$ is the maximum surface of corn grain that can harvested with one combine (ha), $S_{maxStover}$ is the maximum surface of corn grain and stover that can harvested with the single pass harvester (ha), P_{Grain} is the harvest price of corn grain (€/ha), P_{Stover} is the harvest price of corn grain and stover (€/ha), C_{Grain} are the variable costs of harvesting corn grain and C_{Stover} are the variable costs of harvesting corn grain and stover.

For the biogas plant managers, the potential gross margin (PGM) is calculated as the maximum gross margin he can obtain, by optimizing his input plan given the current input prices (Equations B24 – B27).

$$\text{Maximize } \left(\sum_i Q_{i,t}Y_i * \varepsilon\right) * \Big[0.35 * \Big((1 - \varphi_{elec}) * \pi_{elec} + \sigma_{GEC} + \varphi_{elec} * \pi_{elec,avoid}\Big) + 0.5 * \Big((1 - \varphi_{heat}) * \pi_{heat} + \sigma_{GHC} + \varphi_{heat} * \pi_{heat,avoid}\Big)\Big] - (115{,}846 + \left(110 * \sum_{i,t} Q_{i,t}\right) - 691.794 - (Q_{i,t} * P_{i,t})) \tag{B24}$$

s.t.

$$\sum_{i=1}^{n} Q_{i,t} \leq QT \tag{B25}$$

$$Q_{i,t} \geq 0 \tag{B26}$$

$$Q_{corn\ silage,t} + Q_{corn\ stover,t} \geq 0.15 * QT \tag{B27}$$

In Equation B24, $Q_{i,t}$ (ton) is the volume of input i at time t used in the biogas plant, Y_i (m^3 CH_4 / ton,) the methane yield of product i, ε (MWh/m^3) is a conversion factor, ϕ_{elec} and ϕ_{heat} the relative amount of own electricity and heat consumption respectively, π_{elec} (€/MWhe) and π_{heat} (€/MWhth) the revenue from sale of generated electricity and heat respectively, $\pi_{elec,avoid}$ (€/MWhe) and $\pi_{heat,avoid}$ (€/MWhth) the expenses avoided due to own consumption of electricity and heat respectively, σ_{GEC} (€/ MWhe) and σ_{heat} (€/MWhth) subsidies in the form of green electricity certificates and green heat certificates respectively and $P_{i,t}$ the price of input i at time t. This maximisation is done under a number of conditions (Equation B25 – B27). The first condition (Equation B25) ensures that the sum of volumes of each input i is not larger than the maximum capacity of the biogas plant (QT in ton). The second condition (Equation B26) ensures biogas plants cannot devote a negative volume to a certain input. The third condition (Equation B27) ensures that at least 15% of the total inputs is either silage maize or corn stover (Willeghems & Buysse 2016).

A biogas plants AGM is calculated as shown in Equation B28:

$$AGM_{b,t} = \left(\sum_i Q_{i,t} Y_i * \varepsilon\right) * \Big[0.35 * \Big((1 - \varphi_{elec}) * \pi_{elec} + \sigma_{GEC} + \varphi_{elec} * \pi_{elec,avoid}\Big) + 0.5 * \Big((1 - \varphi_{heat}) * \pi_{heat} + \sigma_{GHC} + \varphi_{heat} * \pi_{heat,avoid}\Big)\Big] - (115{,}846 + \left(110 * \sum_{i,t} Q_{i,t}\right) - 691.794 - (Q_{i,t} * P_{i,t})) \quad \text{(B28)}$$

Secondly, uncertainty (U_t) is calculated as shown in Equation B29, in which AGM_{expt} is the agent's expected gross margin. AGM_{expt} is calculated as is shown in Equation B30, in which DF is a discounting factor[22] randomly ranging between 0.2 and 0.8, and AGM_{mean} is the mean of the actual gross margin of the other agents of the same agent type (i.e. biogas plant managers, farmers or custom harvesters).

$$U_{i,t} = \frac{AGMi,_t}{AGM_{expt,i,t}} \quad \text{(B29)}$$

$$AGM_{expt,i,t} = {AGM_{i,t}}^{1-\ DF} * {AGM_{mean}}^{DF} \quad \text{(B30)}$$

The combination of these two variables leads to four behavioural rules that can be followed by the farmers, the custom harvesters, and the biogas plant managers. The first behavioural rule is **repetition**, applied by agents that are economically satisfied and certain about the decisions they make. Therefore, they are not inclined to make any changes to their behaviour. For the farmers, this means that they keep their current cropping plan. For the custom harvesters, this means that they do not consider the option of investing in a new single-pass harvester. For the biogas plant managers, it means that they will keep their current input plan. The second behavioural rule is **imitation**, applied by agents that are economically satisfied, but uncertain that their decisions are the best ones. These agents will scan the behaviour of the other agents, but only in their close network and imitate the behaviour of the best performing ones. Imitating farmers will copy the cropping plan of the farmer with the highest AGM in their close network. Imitating custom harvesters will consider purchasing a single-pass harvester if more than half of the CHs in their close network has already made the investment. Imitating biogas plant managers will copy the input plan of the biogas plant manager with the highest AGM in their close network (Figure B.6). The third behaviour is **social comparison**, applied by economically unsatisfied agents uncertain about their decisions. These agents will look at their broad network instead of their close network, in order to improve their situation. Farmers will copy the cropping plan of the farmer with the highest AHM in their broad network. Custom harvesters will consider purchasing a single-pass harvester if more than half of the custom harvesters in their broad network made the investment before. Biogas plant managers will

[22] The discounting factor represents how much an agent takes into account the revenue gained by other agents of the same agent type.

copy the input plan of the biogas plant manager with the highest AGM in their broad network (Figure B.7). The final behavioural rule is **deliberation**, which is the most economic rational behaviour and is applied by agents, certain about their decisions, but with a low economic satisfaction. Deliberating farmers will maximize their gross margin by optimizing their cropping plan given the current crop prices (Equation B15 – B20). Deliberating biogas plant managers will maximize their gross margin by optimizing their input plan given the current input prices (Equation B24 - B27). Deliberating custom harvesters will consider purchasing a single-pass harvester if the net present value (NPV) of their investment is positive. The net present value is calculated as shown in Equation B31, in which p is the discount rate equal to 0.07. In calculating this NPV, the custom harvester relies on the maximum number of hectares he could harvest yearly for a period of 12 years (Potential revenue).

$$NPV = \sum_{i}^{12} \frac{Potential\ revenue}{(1+p)^i} \qquad \text{(B31)}$$

In all behaviours, custom harvesters considering purchasing a single-pass harvester, will only invest if he is able to actually contract some hectares to harvest.

B.3.2.2. Connection farmers – processors procedure

In this procedure, the farmers sell the corn stover directly to one of the processors, either a biogas plant manager or the manager of the cellulosic sugar production plant. In a first step, farmers calculate the minimum willingness to accept for the stover (minWTA) (Equation B32). In this calculation, they take into account a reduced corn grain yield in corn varieties of which the stover can be harvested. Furthermore, they take into account the additional harvest costs and the transportation costs to the processors.

$$minWTA_i = \left(\left(Yield_{corn\ grain} - Yield_{corn\ grain\ (if\ stover)}\right) *\ P_{corn\ grain}\right) + \frac{HC_{corn\ stover}}{Yield_{corn\ sto}} + TC_{i,p} \qquad \text{(B32)}$$

In Equation B32, $minWTA_i$ is the minimum willingness to accept of farmer i, expressed in €/ton DM, $Yield_{corn\ grain}$ (ton DM/ha) is the yield of corn grain when corn stover is not harvested (ton DM/ha), $Yield_{corn\ grain\ (if\ stover)}$ (ton DM/ha) is the yield of corn grain when both corn grain and stover is harvested, $P_{corn\ grain}$ (€/ton DM) is the price of corn grain, $HC_{corn\ stover}$ is the harvest cost of corn stover (€/ha), $Yield_{corn\ stover}$ is the yield of corn stover (ton DM/ha) and $TC_{i,p}$ is the transportation cost between farmer i and the cellulosic sugar production plant (€/ton DM). The transportation cost depends on the Eucledian distance between the two agents.

The manager of the cellulosic production plant is assigned a maximum willingness to pay (WTP) at the start of the simulations. The biogas plant managers have a maximum willingness to pay, depending on the corn silage prices (Equation B33).

$$maxWTP_{Biogas} = \left(\frac{P_{corn\,silage,t}}{Methane\_Yield_{corn\_silage}}\right) * Methane\_Yield_{corn\_stover} \quad \text{(B33)}$$

in which $P_{corn\ silage,\ t}$ is the price of corn silage in year t, $Methane\_Yield_{corn\_silage}$ fixed at 85 m³ CH_4/ton (Willeghems & Buysse 2016) and $Methane\_Yield_{corn\_stover}$ fixed at 95 m³ CH_4/ton (De Dobbelaere et al. n.d.).

However, as the processors are not willing to bid his full maximum WTP, this value is adjusted using a compromising factor (Cr-factor).

$$bid_{ji} = Cr * maxWTP_j \quad \text{(B34)}$$

$$Cr = \nu^3 \quad \text{(B35)}$$

$$\nu = max[\frac{n}{N}, \frac{t}{T}] \quad \text{(B36)}$$

Next, the processors sends out their price bid to all farmers that want to and are able to sell their stover. Farmers sell the stover to the producer bidding the highest price larger than their minWTA and taking into account transportation costs.

Annex C: ODD-protocol of the agent-based model presented in chapter 4 + sensitivity analysis

C.1. Introduction

In the quest for large amounts of biomass to realize the biobased economy, corn stover currently receives a lot of attention, both from academics as from policy makers. Generally, corn stover is left on the field after the harvest of the grains and a corn stover value chain is almost non-existent. However, today, the technologies exist to convert the corn stover into high value bio-based products, without directly entering in competition with the food or feed chains. Hence, developing such a corn stover value chain might give the biobased economy a major push forward.

However, developing such a corn stover value chain is challenging because of some technical features. As a result, many studies have focused on the techno-economic aspects of the corn stover value chain. Nevertheless, there is still a lack of attention for the organisational issues. Indeed, investments in second generation biomass processing facilities are inherently characterized by uncertainty and irreversibility, which lead to a paralysis, impeding investments and blocking the innovative activities necessary to develop a corn stover value chain. The use of alternative governance structures besides a free-market arrangement, might reduce these uncertainties, allowing a corn stover value chain to develop.

Therefore, we developed an agent-based model (ABM) to investigate the effect of governance structure on the development of a corn stover value chain. This document details the ABM we developed, using the ODD (Overview, Design and Details) protocol. The ODD protocol was developed by Grimm *et al.* (2006) in order to have a standard protocol for describing agent-based models, following a general structure (Grimm et al. 2006; Grimm et al. 2010). The ABM simulates the behaviour of the three main stakeholders involved in the corn stover value chain: farmers, custom harvesters (CHs) and one manager of a central cellulosic sugar production plant. The simulations were done for four governance structures, allowing us to compare a range of hybrid business models with increasing vertical integration.

C.2. Overview

C.2.1. Purpose

The ABM, developed in R (R Core Team 2015), was designed to obtain information about the influence of governance structure on the development of a corn stover value chain. In particular, the model investigates the willingness of farmers to participate, as well as the actual participation rates of farmers and CHs in the corn stover value chain. Furthermore, the model investigates the volume of corn stover traded in the different governance structures. Finally, it should be noted that the goal of the model is not to simulate reality and yield specific numbers, but rather to gain more insights in the influence of different governance structures on the development of a corn stover value chain. This justifies the simplifications made in the ABM.

C.2.2. State variables and scales

C.2.2.1. Structure of the model system

The goal of the model is to simulate the development of a corn stover value chain under different governance structures. Therefore, we have developed a basic model structure and adopted it according to the governance structure applied. Figure C.1 shows a general schematic overview of the model.

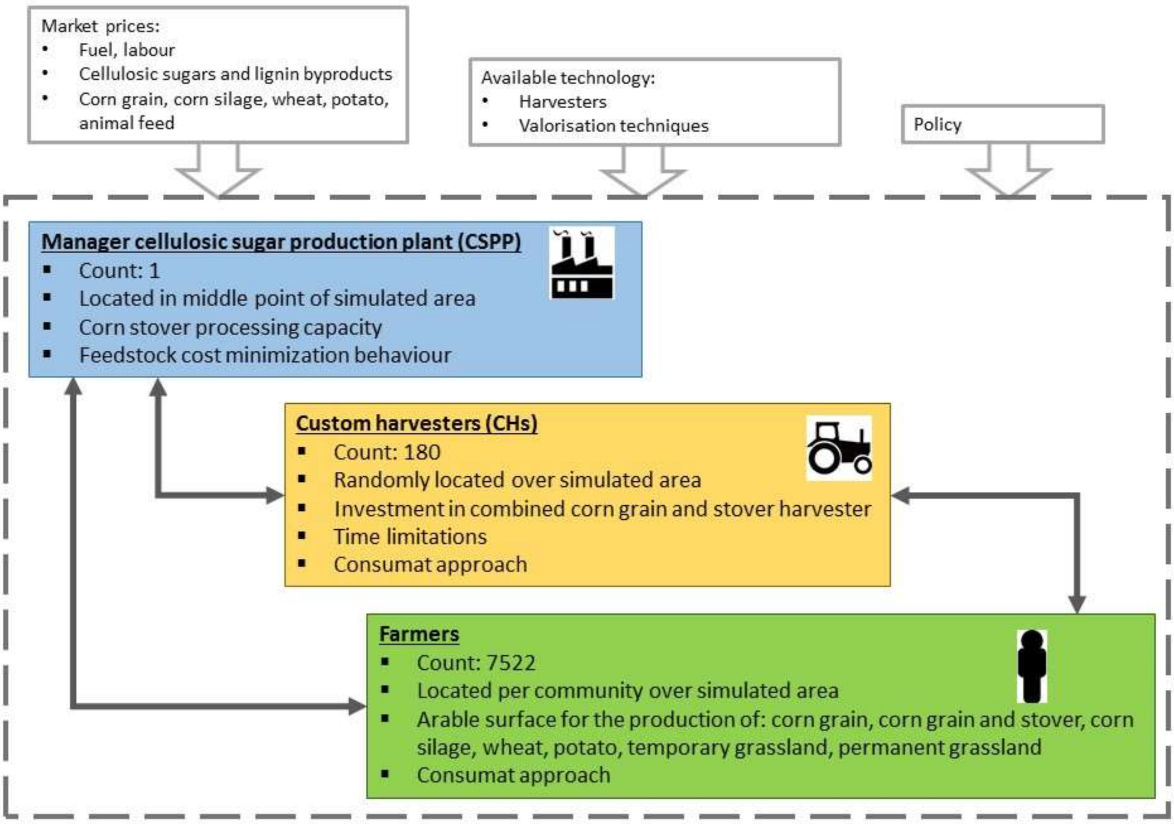


Figure C.1 Schematic overview of the ABM, showing the three considered agent types and their main features. The dashed rectangle represents the model boundary. Parameters mentioned outside the model boundary (large grey arrows) are derived from literature. Agents' behaviour can be affected by these parameters (e.g. crop prices), but the agents have no influence on their value. The dark grey arrows in two directions represent the possible corn stover trade between the agents, depending on the governance structure simulated.

C.2.2.2. Agents

The model includes three main agent types and two additional agent types. The three main agent types are farmers, CHs and one manager of a cellulosic sugar production plant. Grain traders, or traders of the five other crops, as well as buyers of cellulosic sugar and the lignin by-product are exogenously included in the model. Table C.1 shows an overview of the three main explicitly modelled agent types and their attributes. When the business model includes a cooperative, the attribute values of the tasks performed by the cooperative are transferred to the cooperative agent type.

Table C.1 Overview of the explicitly modelled agent types and their attributes

Agent type	Attribute	Value/Range	Distribution	Mean (standard deviation)	Reference
Farmers	Total number	7522			(FOD Economie-Algemene Directie Statistiek 2014)
	Location	According to municipality			(FOD Economie-Algemene Directie Statistiek 2014)
	Aspiration level		Normal	0.4(0.17)	(van Duinen et al. 2016)
	Uncertainty tolerance		Normal	0.9 (0.17)	(van Duinen et al. 2016)
	Discounting factor	0.2 – 0.8	Uniform		(van Duinen et al. 2016)
	Network radius close network (km)	10			
	Transportation cost corn stover (€/ton DM/km)	0.2			Derived from series of semi-structured interviews
	Arable land surface (hectare)				
	Corn grain			7.63	(FOD Economie-Algemene Directie Statistiek 2014)
	Corn for silage			2.88	(FOD Economie-Algemene Directie Statistiek 2014)
	Potato			2.96	(FOD Economie-Algemene Directie Statistiek 2014)
	Wheat			4.47	(FOD Economie-Algemene Directie Statistiek 2014)
	Permanent grassland			4.84	(FOD Economie-Algemene Directie Statistiek 2014)
	Temporary grassland			1.64	(FOD Economie-Algemene Directie Statistiek 2014)
	Yield (ton DM / hectare) (depending on agricultural region)				
	Corn grain	10.57 – 12.30			(FOD Economie-Algemene

					Directie Statistiek 2016)
	Corn grain when harvest stover	9.72 – 11.32			(FOD Economie-Algemene Directie Statistiek 2016)
	Corn stover	7.78 – 9.06			(FOD Economie-Algemene Directie Statistiek 2016)
	Corn for silage	14.52 – 16.57			(FOD Economie-Algemene Directie Statistiek 2016)
	Potato	44.86 – 50.84			(FOD Economie-Algemene Directie Statistiek 2016)
	Wheat	7.82 – 10.07			(FOD Economie-Algemene Directie Statistiek 2016)
	Production costs (€ / hectare)				
	Corn grain	953.3			(LCV 2012)
	Corn for silage	1476.7			(LCV 2012)
	Potato	3172			(De Regt & Deuninck 2010)
	Wheat	1600			(Boeren Op Een Kruispunt n.d.)
	Permanent grassland	913.7			(LCV 2012)
	Temporary grassland	913.7			(LCV 2012)
Custom harvesters	Total number	180			/
	Location		Uniform		/
	Aspiration level		Normal	0.5 (0.17)	(van Duinen et al. 2016)
	Uncertainty tolerance		Normal	0.5 (0.17)	(van Duinen et al. 2016)
	Discounting factor	0.2 – 0.8	Uniform		(van Duinen et al. 2016)
	Discount rate	0.07			(Bral 2014)
	Network probability	0.3			
	Maximum harvest surface grain (hectares/year)	400			Derived from series of semi-structured interviews
	Maximum harvest surface corn + corn stover (hectares / year)	300			Derived from series of semi-structured interviews
	Harvest price grain (€/hectare)	175			Derived from series of semi-structured interviews

	Price single-pass harvester (€)	430,920	(Vadas & Digman 2013)
	Depreciation time (years)	12	(Vadas & Digman 2013)
	Interest rate (%)	2.1	Derived from series of semi-structured interviews
	Insurance cost (€/year)	8618.4	Derived from series of semi-structured interviews
	Repair costs (€/ha)	22.31	Derived from series of semi-structured interviews
	Oils cost (€/year)	3000	Derived from series of semi-structured interviews
	Labour costs (€/hour)	25	Derived from series of semi-structured interviews
	Fuel use (liter/hectare)	17.8	(Vadas & Digman 2013)
	Fuel cost (€/liter)	0.66	Derived from series of semi-structured interviews
	Transportation cost stover (€/ton DM/ km)	0.2	Derived from series of semi-structured interviews
	Risk of no harvest	20%	Derived from series of semi-structured interviews
	Collection efficiency	0.6	Derived from series of semi-structured interviews
CSPP managers	Total number	1	/
	Location	Central in modelled environment	
	Maximum operating capacity (ton DM/year)	250 000	(Duffy & Marchand 2013)
	Production cellulosic sugar (ton DM/ ton corn stover)	0.46	(Duffy & Marchand 2013)
	Production of lignin byproduct (ton DM/ ton corn stover)	0.36	(Duffy & Marchand 2013)
	Price cellulosic sugar (€/ton DM)	362.88	(Duffy & Marchand 2013)
	Price lignin byproduct	36.29	(Duffy & Marchand 2013)

Maximum willingness to pay corn stover (€/ton DM)	117.27	(Duffy & Marchand 2013)
Fixed costs (€/year)	4 109 616	(Duffy & Marchand 2013)
Operating costs (€/ton DM)	362.29	(Duffy & Marchand 2013)

As we investigate the development of a corn stover value chain in Flanders, the agents are dispersed over the surface of Flanders. Farmers are located in the centre of their respective municipality, which could be derived from (FOD Economie-Algemene Directie Statistiek 2014). The CHs are randomly distributed over Flanders. Finally, the cellulosic sugar production plant is located in the geographical centre of Flanders. The figure below shows the configuration of one stochastic realisation. Farmers are indicated with black diamonds, CHs with red dots and the cellulosic sugar production plant with a green square in the middle of the map.

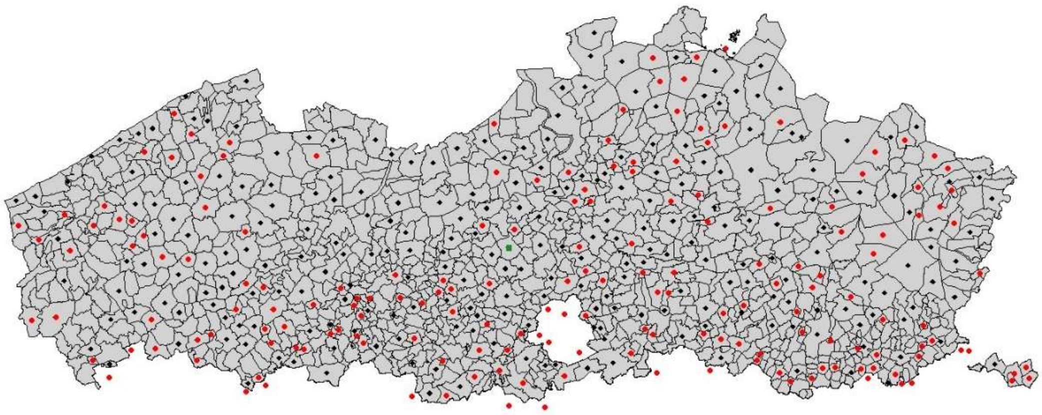


Figure C.3 Representation of the modelled area in one stochastic configuration before the start of a simulation. The black diamonds represent the farmers, the red dots the CHs and the green square the cellulosic sugar production plant.

The model proceeds in annual time steps over a period of 12 years, corresponding to the depreciation time of a combined corn grain and stover harvester. There is no hierarchical difference between the farmers, the CHs and the manager of the cellulosic sugar production plant, meaning that these agents operate at the same level. In case there is a supply cooperative or a bioprocessing cooperative, members of the cooperative are aggregated. Hence, the cooperative acts as a single agent, representing its members. This will be explained in more detail below.

Finally, several auxiliary variables are included in the model, available to all agents in the model

- Crop prices for corn grain, corn silage, potato and wheat in €/ton DM for the years 2003 – 2014 (Wageningen UR 2014).
- Values for temporary grassland and permanent grassland are expressed in €/hectare for the years 2003 – 2014 (Wageningen UR Livestock Research 2014).

C.2.2.3. Markets

The model simulates the development of the corn stover value chain. Hence, the trade of corn stover is explicitly modelled and can be influenced by the agents.

Besides growing corn for corn stover, farmers have the option to grow six other crops: corn for grain harvest only, corn silage, wheat, potato, temporary grassland and permanent grassland. The reason for the selection of these crops was that they represented 95% of the total arable surface cultivated by farmers that grow corn grain in 2010. The markets of these crops are exogenously determined, meaning that the crop prices can influence the farmers' behaviour. On the other hand, the farmers' decisions have no direct influence on the market prices for these crops. The market prices were derived from (Wageningen UR 2014).

Furthermore, the agents' profits are influenced by fuel and labour prices, next to cellulosic sugars and lignin by-product prices. However, the behaviour agents themselves cannot influence these markets (Figure C.1).

C.2.3. Process overview and scheduling

The ABM developed was applied to four governance structures with increasing vertical integration derived from (Duffy & Marchand 2013) (Figure C.3).

The first governance structure simulated is a corn stover spot market, called "Direct sale". In this governance structure, farmers interested in selling stover negotiate individually with the manager of the cellulosic sugar production plant about the corn stover price. In this governance structure, farmers are responsible for the harvesting and transportation of the stover to the cellulosic sugar production plant. Therefore, they need to find a custom harvester that is willing to invest or has already invested in a single-pass harvester. As a result, farmers also bear the costs of these activities. In the second governance structure simulated, "Request-for-purchase", the CHs act as intermediaries between the farmers and the manager of the cellulosic sugar production plant. Participating CHs contract a certain volume of stover to be delivered to the cellulosic sugar production plant at a certain price. Hence, in this case, the CHs are responsible for the harvest and transportation costs. In a next step, the CHs look for farmers that want to sell their corn stover. In the third governance structure simulated a supply cooperative is established, having interested farmers and CHs as members. The supply cooperative aims to organise the harvest and transport of stover as efficiently as possible and negotiates as a single entity about the corn stover supply conditions with the manager of the cellulosic sugar production plant. Finally, in the fourth governance structure, a bioprocessing cooperative is established, having interested farmers and CHs as members. In this governance structure the cooperative also manages the cellulosic sugar production plant. The goal of the bioprocessing coop is to organise the corn stover supply chain as efficiently as possible. Each member also shares in the profit made by the cellulosic sugar production plant.

Figure C.4 shows a general overview of the main model procedures for the four business models. Different model procedures are recurrent in the four business models, however due to different ordering of procedures and/or differing details, the model results can differ greatly. We will discuss each of these model procedures in detail below.

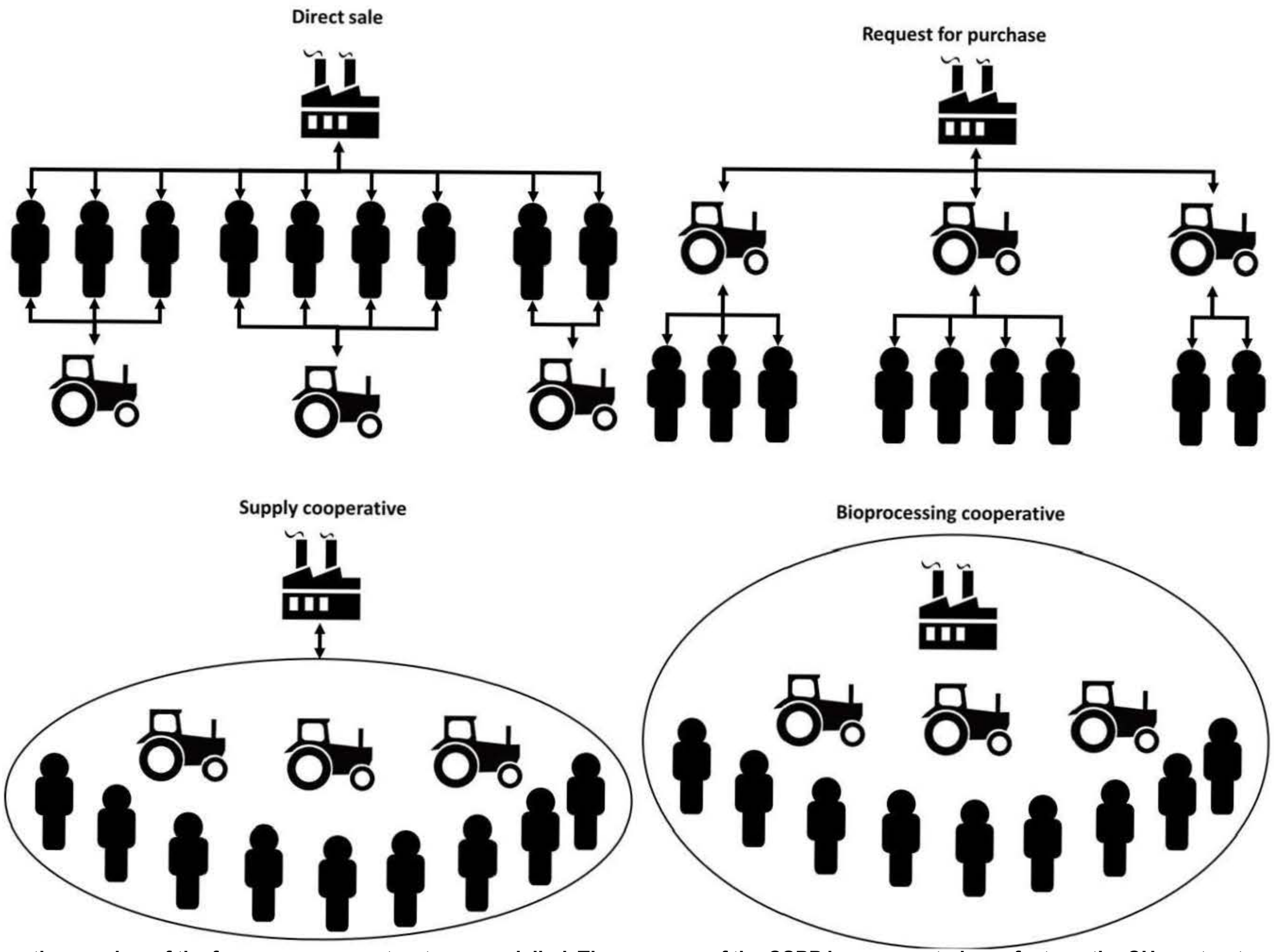


Figure C.4 Schematic overview of the four governance structures modelled. The manager of the CSPP is represented as a factory, the CHs as tractors and the farmers as persons. Two-sided arrows represent negotiation processes.

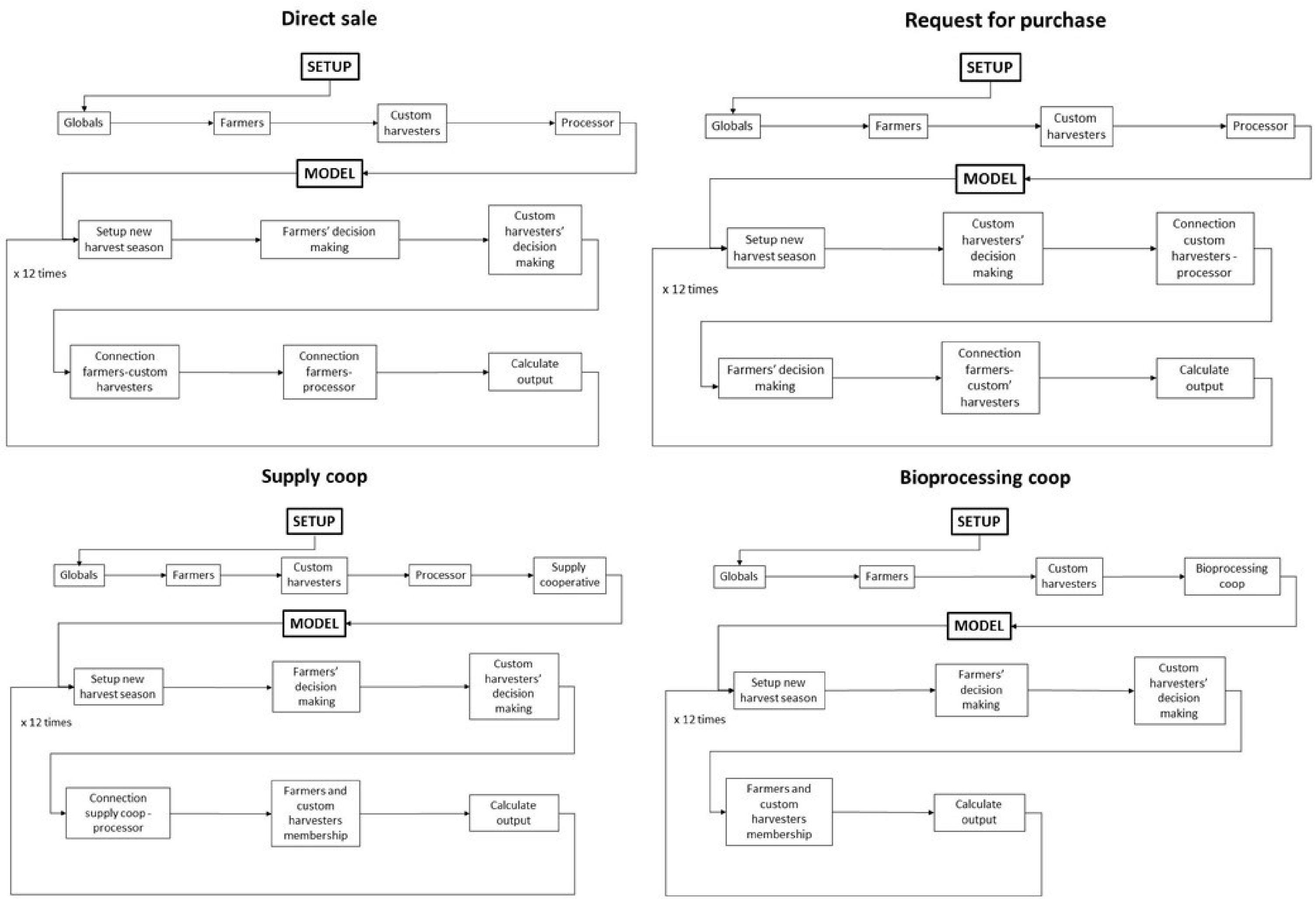


Figure C.5 Schematic overview of the main model procedures for the four business models.

C.2.3.1. Setup

At the start of each simulation, a setup procedure is executed which initializes the auxiliary variables (globals), farmers, CHs and the simulation environment. In case of a supply cooperative governance structure, the supply cooperative is set up as an additional actor. In case of a bioprocessing cooperative business model, the processor is not initialised, but integrated in the setup of the bioprocessing cooperative.

At the start of the simulations, each farmer in the model is connected to other farmers by means of a network. A farmer's close network contains all farmers within a radius of 10 kilometres from the farmer (Table C.1). A farmer's broad network contains all farmers within the same agricultural area. CHs are connected through an Erdös-Renyi network (Peres 2014), in which each CH has a probability of 0.3 to be connected to another CH. Each of these connections is randomly assigned a value, which represents the strength of the connection. Connections with a value equal or larger than 0.5 represent a CH's close network, connections with a value between 0 and 0.5 represent a CH's broad network. Finally, upon initialisation, each farmer is assigned to a CH, meaning that that particular CH is responsible for harvesting the farmer's corn grain. These connections are primarily based on smallest distance. However, when a CH has already reached his maximum capacity of 400 hectares, the farmer is assigned to the nearest CH that has less than 400 hectares of corn grain under contract.

C.2.3.2. Setup new harvest season

After the setup, the actual simulations are started. In total, the model is repeated 12 times, simulating a total period of 12 years. Each year, a new harvest season is initialized. This means that some agents' parameters are reset to their initial values. These values are presented in Table C.2.

Table C.2 Parameters reset after each simulated year

Parameter	Value
Farmers	
Highest offer for stover (€/ha)	0
Processor contract	0
Stover supply (ton DM)	0
Interest in selling stover	False
Total Income (€)	0
Custom harvesters	
Interest in investing in combined corn grain and stover harvester	False
NPV	0
Number of hectares to harvest stover under contract	0
Largest offer for harvesting stover (€ / ha)	0
Processor contract	0
Number of hectares purchased (ha)	0
Processor	
Number of custom harvesters under contract	0
Stover price offer (€/ha)	0
Volume of stover purchased (ton DM)	0

Number of hectares of stover purchased (ha)	0
Total stover cost (€)	0
Average stover cost (€/ton DM)	0
Total expenses (€)	0
Supply coop / Bioprocessing coop	
Number of hectares under contract	0
Number of custom harvesters under contract	0
Number of hectares possible to harvest (ha)	0
Actual stover supply (ton DM)	0
Net income (€)	0
Extra dividend for farmers (€/ton DM)	0
Extra dividend for contractors (€/ha)	0

C.2.2.3. Farmers' and custom harvesters' decision making procedure

The farmers' and CHs' decision making procedure is schematically represented in Figure C.6 In this procedure, the two agent types start calculating their potential gross margin. A farmer's potential gross margin is the maximum gross margin per hectare a farmer can obtain, by optimizing his cropping plan given the current crop prices. For the CHs, the potential gross margin is calculated as the maximum gross margin they can generate, given the machinery they have. Next, the agents calculate the actual gross margin. For the farmers, this calculation is based on the current prices and the production costs for each crop in their cropping plan. For the CHs, the calculation of the AGM is based on the machinery they have and the amount of hectares they have under contract to harvest.

Based on the actual and the potential gross margin, the agents determine their economic satisfaction (ES) which can be regarded as a proxy for the answer to the question "Am I happy with the revenue I generated, given my current assets (arable land or harvesters). The ES is calculated as the ratio of an agent's actual gross margin over his potential gross margin. The second variable is uncertainty (U), which is a proxy for the answer to the question: "How certain am I that the cropping/ machinery investment decisions I made were good decisions I could have made given the average economic performance of the other farmers or CHs?"

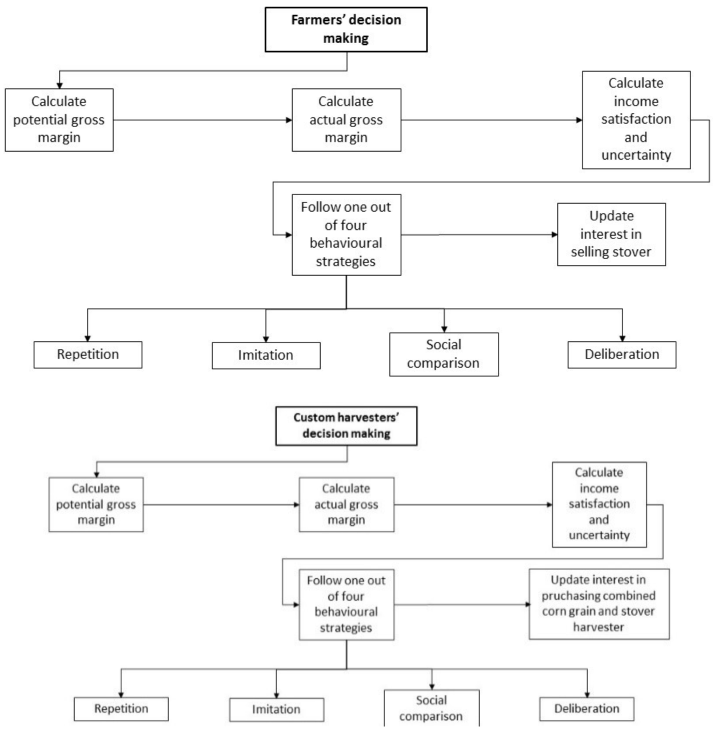


Figure C.6 Schematic overview of the farmers' and CHs' decision making procedures

The combination of the economic satisfaction and uncertainty lead to four different behavioural rules that can be followed by the farmers and the CHs (Figure C.7 and Figure C.8). These behavioural rules are derived from the "Consumat meta-model" as described by (Jager et al. 2000) and the related model developed by (van Duinen et al. 2016). The Consumat meta-model was developed as an attempt to incorporate the major behavioural theories of behavioural economics, transaction costs economics and psychology in one comprehensible behavioural model for agents (Jager et al. 2000).

The first behavioural rule is **repetition**, applied by agents that are economically satisficed and certain about the decisions they make. Therefore, they are not inclined to make any changes to their behaviour. For the farmers, this means that they keep their current cropping plan. For the CHs, this means that they do not consider the option of investing in a new single-pass harvester.

The second behavioural rule is **imitation**, applied by agents that are economically satisficed, but uncertain that their decisions are the best ones. Therefore, they will scan the behaviours in their close network and imitate the behaviour of the agent that performs best. Hence, imitating farmers will copy the cropping plant of the farmer with the highest actual gross margin in his close network. Imitating CHs will consider in purchasing a single-pass harvester if more than half of the CHs in their close network has invested in one (Figure C.8)

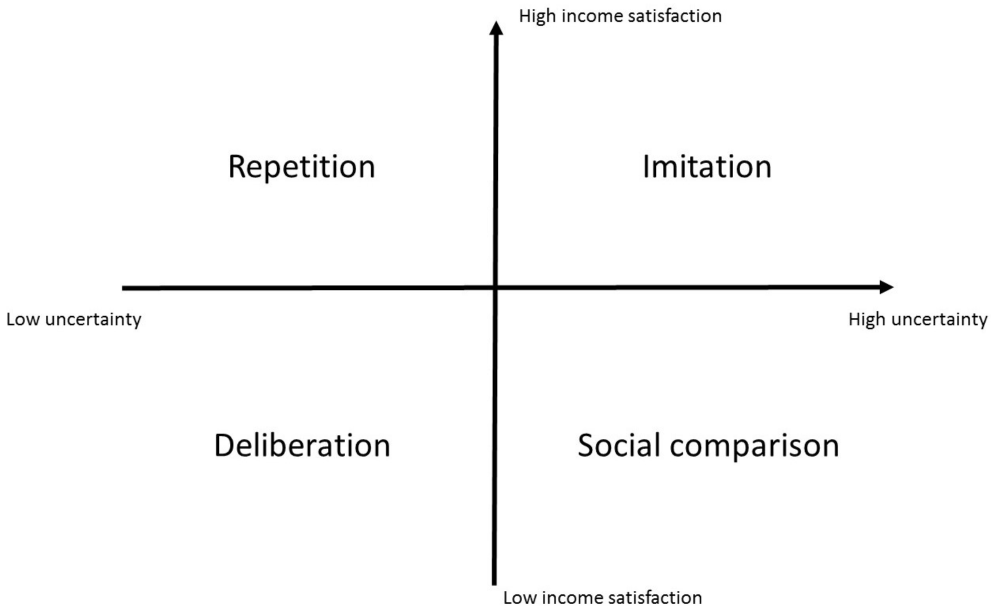


Figure C.7 Four behavioural rules applied by the farmers and the custom harvesters included in the agent-based model derived from the Consumat meta-model.

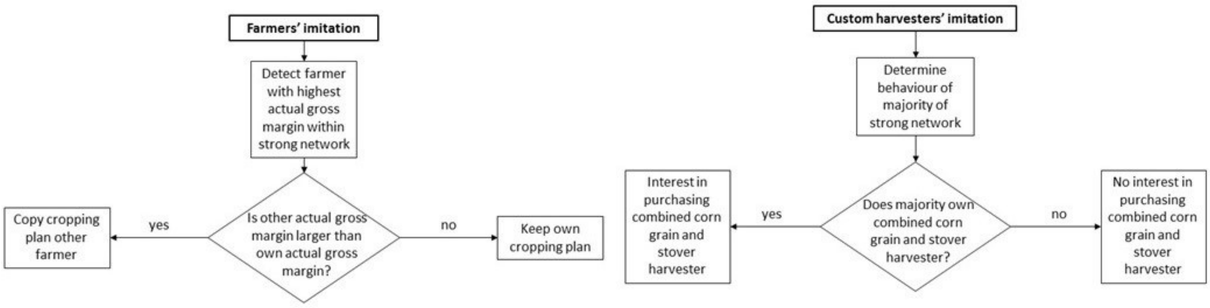


Figure C.8 Schematic overview of the behavioural rule "Imitation" applied by farmers and CHs

The third behaviour is **social comparison**, applied by economically unsatisfied agents uncertain about their decisions. These agents will look into their broad network in order to discover how they can improve their situation. Farmers will in this case copy the cropping plan of the farmer with the highest actual gross margin in their broad network. CHs will consider purchasing a single-pass harvester is more than half of the CHs in their broad network has invested in one (Figure C.9).

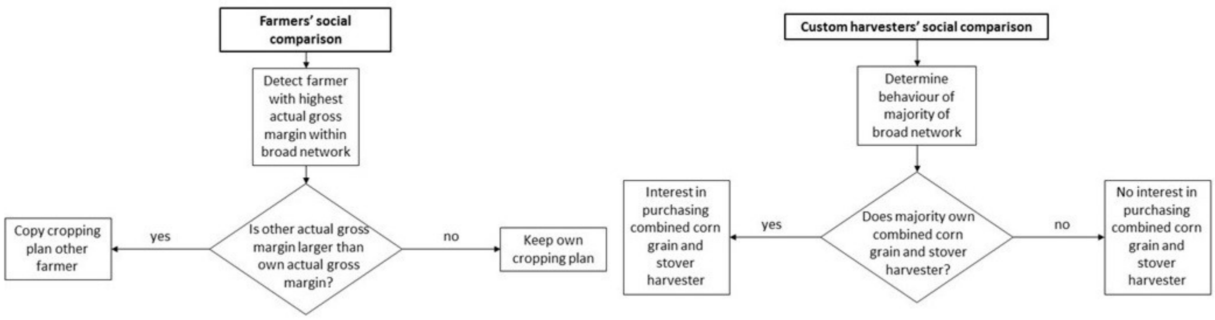


Figure C.9 Schematic overview of the behavioural rule "Social comparison" applied by farmers and CHs

The fourth behaviour, **deliberation**, is the most economic rational behaviour and is applied by agents certain about their decisions but with a low economic satisfaction. Deliberating farmers will optimize their revenue by adjusting their cropping plan given the current crop prices (see equations C1 – C6). Deliberating CHs will consider purchasing a single-pass harvester if the net present value (NPV) of their investment is positive (Figure C.10).

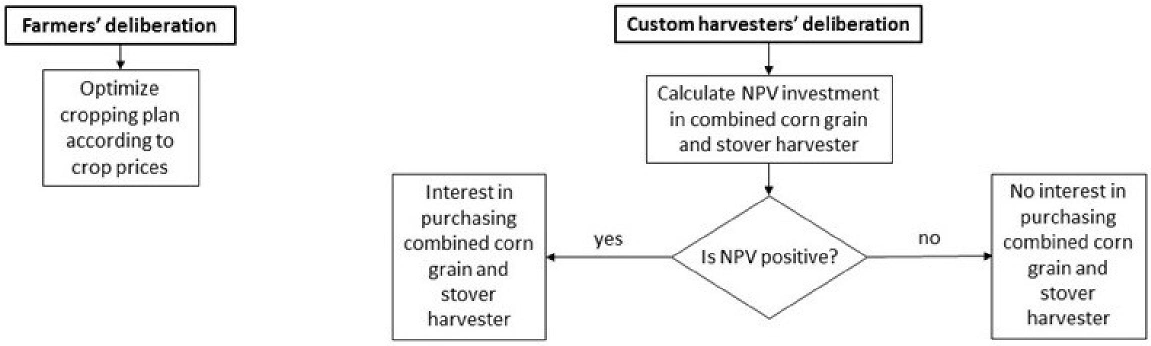


Figure C.10 Schematic overview of the behavioural rule "Deliberation" applied by farmers and CHs.

C.2.2.4. Connection farmers – custom harvesters procedure

In this procedure, the farmers that want to harvest their stover seek for the closest custom harvester that owns the single-pass harvester or is willing to invest in one. In making the requests, priority is given to CHs that already own a harvester. The custom harvester accepts the requests until he reached the maximum amount of hectares he can harvest with the harvester (300 hectares per year). If the custom harvester cannot accept any more requests, the farmer will look for the second closest, and so on. Every custom harvester that is interested in buying a single-pass harvester will make the purchase if he has had a request from a farmer. Finally, farmers that have found a custom harvester that has the necessary harvesting equipment will also switch to this harvester for the harvesting of corn grains of fields from which they do not want to harvest the stover. Farmers that were willing to harvest stover but were not able to set up a contract with a custom harvester will grow corn for the harvest of the corn grains only on the surfaces originally destined for growing corn for grain and stover harvest.

C.2.2.5. Connection farmers – processor procedure

In this procedure, the farmers sell the corn stover directly to the manager of the cellulosic sugar production plant. In a first step, farmers calculate the minimum willingness to accept for the stover (WTA). In this calculation, they take into account a reduced corn grain yield in corn varieties of which the stover can be harvested. Furthermore, they take into account the additional harvest costs and the transportation costs to the cellulosic sugar production plant. The manager of the cellulosic production plant is assigned a maximum willingness to pay (WTP) at the start of the simulations. However, as he is not willing to offer his full maximum

WTP, this value is adjusted using a compromising factor (Cr-value) This is explained in more detail in section 2 and 3.2.2. Next, the manager sends out this price offer to all farmers that are willing and able to sell stover. The farmers accept the offer it is larger than their minimum WTA. If not, they will plant corn for the harvest of grains only.

C.2.2.6. Connection custom harvesters – processor procedure

In this procedure, part of the request-for-purchase business model, the manager of the cellulosic sugar production plant and the CHs will first set up a contract with each other, before the CHs set up a contract with the farmers. Therefore, the manager sends out a price offer to the CHs, based on the maximum WTP. However, and similar to the previous procedure, the manager is not willing to offer the full max WTP. Therefore, this value is adjusted using a compromising factor (Cr-value). This is explained in more detail in section 2 and 3.2.2. The CHs that are interested to invest in a combined corn grain and stover harvester receive these offers, and calculate the NPV of their investment based on this offer. If the NPV is positive and the price offered is larger than the minimum WTA of the custom harvester, the custom harvester will accept the offer and set up a contract with the manager of the cellulosic sugar production plant. In calculating the minimum WTA, the CHs take into account the fact that they are responsible for the harvest and transportation costs, and the fact that they need to pay the farmers at least their minWTA for the stover.

C.2.2.7. Connection farmers – custom harvesters in request-for-purchase governance structure

In this procedure, CHs make a price offer to the farmers that are interested to sell stover. This price offer is based on their maximum WTP, which depends on the contract price they have previously received from the manager of the cellulosic sugar production plant, the transportation costs, and the harvest costs. Furthermore, as the CHs are not willing to offer their full maximum WTP, they adjust the value using a compromising factor (Cr-factor). This is explained in more detail in section 2 and 3.2.2. The farmers that are interested in selling their stover receive these offers. They notify the custom harvester that made the largest offer to them that they want to set up a contract with him. Out of these notifications, the custom harvester picks the closest farmers to his location, until he has reached his maximum harvesting surface. Finally, farmers that have found a custom harvester that has the necessary harvesting equipment will also switch to this harvester for the harvesting of corn grains of fields from which they do not want to harvest the stover. Farmers that were willing to harvest stover but were not able to set up a contract with a custom harvester will grow corn for the harvest of the corn grains only on the surfaces originally destined for growing corn for grain and stover harvest.

C.2.2.8. Connection supply coop – processor

After the farmers' and CHs' decision making, the supply cooperative registers all farmers and CHs that are interested to take part in the corn stover supply chain. Based on the amount of stover the supply cooperative can supply to the cellulosic sugar production plant, the price of the stover delivered to the plant is negotiated. This is done based on the maximum WTP of the manager of the cellulosic sugar production plant, adjusted with the help of a compromising factor (Cr-value). This is explained in more detail in section 2 and 3.2.2. Based on the negotiated price and a certain division rate, the supply cooperative determines the stover price for the farmers and the harvest price for the contractors.

C.2.2.9. Farmers and custom harvesters membership

In this procedure, the cooperative regulates the membership of both the farmers and the CHs based on the amount of stover that can maximally be harvested. This is either dependent on the number of farmers that want to participate if the number of hectares planted with maize for corn grain and stover harvest is smaller than the number of hectares that can be harvested given the combined corn grain and stover harvesters available, or on the number of CHs involved if the number of combined corn grain and stover harvesters available is smaller than the number of hectares planted with maize for corn grain and stover harvest. The farmers and CHs are selected in this way, that the farmers involved are located as close as possible to the CHs involved.

C.2.2.10. Calculate output

Every simulation cycle the model output is calculated and stored in a matrix. The output variables are:

- The simulation cycle
- Year in the simulation cycle
- Business model
- Number of farmers with repeating behaviour
- Number of farmers with deliberating behaviour
- Number of farmers with imitating behaviour
- Number of farmers with social comparative behaviour
- Total hectares of corn grown for corn grain only
- Total hectares of corn grown for corn grain and corn stover
- Total hectares of corn grown for silage
- Total hectares of potatoes
- Total hectares of wheat

- Total hectares of permanent grassland
- Total hectares of temporary grassland
- Number of farmers willing to sell corn stover
- Number of farmers actually selling corn stover
- Average corn stover supply per farmer
- Number of CHs with repeating behaviour
- Number of CHs with deliberating behaviour
- Number of CHs with imitating behaviour
- Number of CHs with social comparative behaviour
- Number of CHs with a combined corn grain and stover harvester
- Volume of corn stover purchased by the manager of the cellulosic sugar production plant
- Average corn stover price paid by the manager of the cellulosic sugar production plant
- Average corn stover farm gate price received by the farmers
- Total revenue made by the manager of the cellulosic sugar production plant
- Net income of the manager of the cellulosic sugar production plant

Additionally, for all individual agents, the different parameters and variables are saved in separate csv-files for each agent type. This allowed us to double check the results.

C.3. Design concepts

C.3.1. Basic principles

The goal of the ABM is to be able to investigate the development of a corn stover value chain when different governance structures are applied. Different information sources contributed to design of the agent-based model. Firstly, in order to gain a first general insight into the opportunities and challenges related to the establishment of a corn stover value chain, we conducted semi-structured interviews with experts and possible stakeholders, including farmers and CHs. Next, a literature study was conducted on the techno-economic aspects of corn stover harvest, logistics and processing (Petrolia 2008; Hess et al. 2009; Thompson & Tyner 2014; Gan et al. 2014; Sokhansanj et al. 2002; Sokhansanj et al. 2010; Babcock et al. 2011; Aden & Foust 2009). In addition, we did some literature study on the organisational aspects of biomass supply chains (e.g. (Altman & Sanders 2012; Endres et al. 2013; Weseen et al. 2014; Ferrari et al. 2016)). Finally, in order to conceptualize the decision behaviour of the farmers and the CHs, the Consumat approach was included in the model (Jager et al. 2000; van Duinen et al. 2016). After a preliminary version of the model was developed, a workshop was organized for different experts of corn stover harvest, logistics and processing. In this workshop, with 9 participants, the model and the preliminary results were presented and feedback given by the participants was taken into account to build the final model version.

C.3.2. Emergence

The model allows us to observe the development of a corn stover value chain when different governance structures are applied. Applying different governance structures influences how the innovation of corn stover harvest and processing is adopted by the farmers and the CHs. Additionally, the simulations give insight in the stability of the corn stover supply over time to the centralized processor. Corn stover pricing is more tightly imposed on the model and can therefore not be regarded as an emergent phenomenon.

C.3.3. Adaptation

Adaptation is included at different points in the ABM. Firstly, with regard to the behavioural rules for making decisions, we applied the Consumat approach based on (Jager et al. 2000; van Duinen et al. 2016) for the farmers and the CHs. The behavioural rules lead to farmers adjusting their cropping plan and the option for CHs to purchase a combined corn grain and stover harvester. In this sense, the adaptive trait is a way agents seek to increase their success, namely their actual gross margin. The way the agents adapt their behaviour is explained in more detail below.

Another adaptive trait is included regarding the corn stover purchasing behaviour When an agent, either a custom harvester or the manager of the cellulosic sugar production plant, wants to purchase stover, he is not willing to make an offer equal to his maximum willingness to pay, but prefers to pay a lower price. Therefore, the sale and purchase of stover in these procedures is modelled as a sealed bid auction repeated multiple times in order to simulate a negotiation process. In total the negotiation procedure is repeated 6 times, simulating the 6 months between the harvest of the maize crop and the planting of the new crops. In each negotiation round, the buying agent, adjusts his maximum offer by multiplying it with a compromising factor (Cr-factor), in analogy with (Shastri et al. 2011). This Cr-factor is calculated using Equation C1 and Equation C2.

$$Cr = v^3 \tag{C1}$$

$$v = max[\frac{n}{N}, \frac{t}{T}] \tag{C2}$$

with n the amount of corn stover the agent was already able to purchase, N the agent's total stover demand (N), t the number of auction rounds before the season is over and T the total number of bidding rounds.

C.3.4. Objectives

As explained before, agents adjust their behaviour to increase their actual gross margin compared to their potential gross margin. The potential gross margin is calculated as the maximum gross margin per hectare a farmer can obtain, by optimizing his cropping plan given the current crop prices (Equations C3 – C8).

$$Maximise: \sum_{c=1}^{n} ((Y_{i,c} * P_{c,t}) - C_c) * S_{i,c,t} \tag{C3}$$

subject to (s.t.)

$$\sum_{c=1}^{n} S_{i,c,t} \leq ST_i \tag{C4}$$

$$S_{i,c,t} \geq 0 \tag{C5}$$

$$S_{i,perm\ grass,t} \geq 0.05 * ST_i \tag{C6}$$

$$S_{i,c,t} \leq 0.75 * ST_i \tag{C7}$$

$$S_{i,potato,t} \leq \frac{1}{3} * ST_i \tag{C8}$$

In Equation C3, $Y_{i,c}$ is the yield of crop c produced by farmer i (ton DM/ha), $P_{c,t}$ is the price for crop c in year t (€/ton DM), C_c the production costs of crop c (€/ha), $S_{i,c,t}$ the surface of crop c grown by farmer i in year t (ha). Hence, Equation C3 maximises the gross margin a farmer can obtain. This maximisation is done under a number of conditions (Equation C4 – C8). The first condition (Equation C4) ensures that the sum of the arable land devoted by farmer i to each crop is not larger than the total arable surface available to farmer i (ST_i in ha). The second condition (Equation C5) ensures farmers cannot devote a negative arable surface to a certain crop. The third condition (Equation C6) ensures that at least 5% of the total arable land cultivated by farmer i is devoted the cultivation of permanent grassland ($S_{i,perm\ grass,\ t}$ in ha). The fourth condition (Equation C7) ensures that one crop does not take more than 75% of the total arable land cultivated by farmer i. Finally, the last condition (Equation C8) ensures that the obliged rotation for potato, which states that potatoes can only be grown on the same land every three years, is fulfilled. In case of a supply coop or a bioprocessing coop, an extra constraint is added (Equation C9), which ensures that once a farmer decides to become a member of a coop, he will keep his membership:

$$S_{i,stover,t} \geq S_{i,stover,t-1} \tag{C9}$$

The actual gross margin is calculated as presented in Equation C10.

$$AGM_{i,t} = Y_{i,t} = \frac{\sum_{i=1}^{n}((P_{c,t} * Y_{i,c} * S_{i,c,t}) - (C_c * S_{i,c,t}))}{ST_i} \quad \text{(C10)}$$

For the CHs, the actual gross margin is calculated as shown in Equation C11.

$$AGM_{i,t} = (HS_{i,actGrain} * (HP_{Grain} - HVC_{Grain})) + (HS_{i,actStover} * (HP_{Stover} - HVC_{Stover}) \quad \text{(C11)}$$

In Equation C11, $HS_{i,actGrain}$ is the actual harvested surface of corn grain by custom harvester i (ha), $HS_{i,actStover}$ is the actual harvested surface of corn stover by custom harvester i (ha), $HS_{maxGrain}$ is the maximum surface of corn grain that can harvested with one combine (ha), $HS_{maxStover}$ is the maximum surface of corn grain and stover that can harvested with the single pass harvester (ha), HP_{Grain} is the harvest price of corn grain (€/ha), HP_{Stover} is the harvest price of corn grain and stover (€/ha), HVC_{Grain} are the variable costs of harvesting corn grain and HVC_{Stover} are the variable costs of harvesting corn grain and stover.

C.3.5. Learning

Learning is not explicitly included in the model.

C.3.6. Prediction

Prediction is not explicitly included in the model.

C.3.7. Sensing

In the model, the farmers are aware of the crop prices and the cultivation costs. Moreover, farmers and CHs are aware of the average actual gross margin of the other agents of the same agent type, which they use to calculate their uncertainty value.

Furthermore, at the start of the simulations, each farmer in the model is connected to other farmers by means of a network. A farmer’s close network contains all farmers within a radius of 10 kilometres from the farmer (Table C.1). A farmer’s broad network contains all farmers within the same agricultural area. CHs are connected through an Erdös-Renyi network (Peres 2014), in which each CH has a probability of 0.3 to be connected to another CH. The agents are aware of the decisions of the other agents in their network. For the farmers, this means that they are aware of the cropping plan of the other farmers in their network. The CHs know which other CHs in their network own a combined corn grain and stover harvester. This knowledge is used by the farmers and the CHs to make their decisions in the imitation and social comparison decision rule.

C.3.8. Interaction

Direct interaction between agents takes place when corn stover is traded and agents involved negotiate on the corn stover price (two-sided arrows in Figure C.3). Depending on the governance structure simulated, this trade takes place between the farmers and the CHs, between the farmers and the manager of the cellulosic sugar production plant, or between the CHs and the manager of the cellulosic sugar production plant. As explained before, trading of corn stover is done using a negotiation process. Furthermore, there is direct interaction between farmers and CHs when corn stover is harvested.

Indirect interaction amongst farmers and amongst CHs takes place, when these agents compare their own actual gross margin to the average actual gross margin of their respective agent type.

Communication between the agents is not explicitly modelled.

C.3.9. Stochasticity

There are several state variables that are randomly initialized:

- Farmers:
    - Farmers are assigned a random aspiration level value with a mean of 0.5 and a standard deviation of 0.17.
    - Farmers are assigned a random uncertainty tolerance value with a mean of 0.5 and a standard deviation of 0.17
    - Farmers are assigned a random discounting factor ranging between 0.2 and 0.8.
- CHs:
    - CHs are randomly located over the simulated area.
    - CHs are assigned a random aspiration level value with a mean of 0.5 and a standard deviation of 0.17.
    - CHs are assigned a random uncertainty tolerance value with a mean of 0.5 and a standard deviation of 0.17.
    - CHs are assigned a random discounting factor ranging between 0.2 and 0.8.
    - Upon initialisation, an Erdös-Renyi network is created amongst the CHs with a network probability of 0.3.

Finally, the order in which farmers and CHs execute the procedures is random.

C.3.10. Collectives

Aggregation of agents happens in two ways. Firstly, in the cooperative governance structures, cooperatives are formed, having both farmers and CHs as members. This collective can be regarded as emergent, as the way it develops depends on farmers and CHs wanting to participate in the corn stover value chain and becoming members. Secondly, networks are formed amongst farmers and CHs. These networks are not emergent, but formed upon initialisation.

C.3.11. Heterogeneity

Farmers and CHs are heterogeneous with regard to their state variables (Table C.1) and the decision rules they follow.

C.3.12. Observation

Following output is generated by the model:

- Number of farmers with repetitive behaviour
- Number of farmers with deliberating behaviour
- Number of farmers with social comparing behaviour
- Number of farmers with imitating behaviour
- Total amount of hectares grown with corn for the harvest of grains only over the modelled surface
- Total amount of hectares grown with corn for silage production over the modelled surface
- Total amount of hectares grown with corn for the harvest of grains and stover over the modelled surface
- Total amount of hectares grown with potato over the modelled surface
- Total amount of hectares grown with wheat over the modelled surface
- Total amount of hectares grown with permanent grassland over the modelled surface
- Total amount of hectares grown with temporary grassland over the modelled surface
- Number of farmers willing to participate in the corn stover value chain
- Number of farmers actually participating in the corn stover value chain
- Average volume of stover delivered to the cellulosic sugar production plant per delivering farmer
- Number of CHs with repeating behaviour
- Number of CHs with deliberating behaviour
- Number of CHs with social comparing behaviour
- Number of CHs with imitating behaviour
- Number of contractors owning a single-pass harvester
- Total volume of corn stover purchased by the manager of the cellulosic sugar production plant (ton DM)

- Average stover gate fee price paid by the manager of the cellulosic sugar production plant (€/ton DM)
- Average stover farm gate price received by the farmers (€/ton DM)
- Total revenue of the cellulosic sugar production plant
- Net income of the cellulosic sugar production plant

These outcomes were calculated each simulation round and then stored into a csv-file. The resulting csv-file was then analysed using Excel and R. We included data of all agents for the analysis.

C.4. Details

C.4.1. Initialization and input data

A detailed description of the initialisation data can be found in Table C.1. Most of these data were based on literature or retrieved from interviews. Some of these data, network probability, the number of CHs and the location of the CHs, were arbitrarily chosen as no data were available.

Each simulation round, some state variables are re-initialised. These are presented in Table C.2.

C.4.2. Submodels

In this section, the different submodels of the ABM are discussed, including their equations. We will only discuss the submodels which contain equations.

C.4.2.1. Farmers' and custom harvesters' decision making procedure

As explained before, farmer's and CHs' decision making procedure, depends on two variables: economic satisfaction and uncertainty. In the model, economic satisfaction is calculated as the ratio of an agent's actual gross margin (AGM or $Y_{i,t}$) over his potential gross margin (PGM or $Y_{i,t}^{*}$).

The potential gross margin is calculated as the maximum gross margin per hectare a farmer can obtain, by optimizing his cropping plan given the current crop prices (Equation C12 – C18).

$$Maximise: \sum_{c=1}^{n}((Y_{i,c} * P_{c,t}) - C_c) * S_{i,c,t} \quad \text{(C12)}$$

subject to (s.t.)

$$\sum_{c=1}^{n} S_{i,c,t} \leq ST_i \quad \text{(C13)}$$

$$S_{i,c,t} \geq 0 \quad (C14)$$

$$S_{i,perm\ grass,t} \geq 0.05 * ST_i \quad (C15)$$

$$S_{i,c,t} \leq 0.75 * ST_i \quad (C16)$$

$$S_{i,potato,t} \leq \frac{1}{3} * ST_i \quad (C17)$$

In Equation C11, $Y_{i,c}$ is the yield of crop c produced by farmer i (ton DM/ha), $P_{c,t}$ is the price for crop c in year t (€/ton DM), C_c the production costs of crop c (€/ha), $S_{i,c,t}$ the surface of crop c grown by farmer i in year t (ha). Hence, Equation C12 maximises the gross margin a farmer can obtain. This maximisation is done under a number of conditions (Equation C12 – C18). The first condition (Equation C12) ensures that the sum of the arable land devoted by farmer i to each crop is not larger than the total arable surface available to farmer i (ST_i in ha). The second condition (Equation C13) ensures farmers cannot devote a negative arable surface to a certain crop. The third condition (Equation C14) ensures that at least 5% of the total arable land cultivated by farmer i is devoted the cultivation of permanent grassland ($S_{i,perm\ grass,\ t}$ in ha). The fourth condition (Equation C15) ensures that one crop does not take more than 75% of the total arable land cultivated by farmer i. Finally, the last condition (Equation C16) ensures that the obliged rotation for potato, which states that potatoes can only be grown on the same land every three years, is fulfilled. In case of a supply coop or a bioprocessing coop, an extra constraint is added (Equation C18), which ensures that once a farmer decides to become a member of a coop, he will keep his membership:

$$S_{i,stover,t} \geq S_{i,stover,t-1} \quad (C18)$$

The actual gross margin is calculated as presented in Equation C19.

$$AGM_{i,t} = Y_{i,t} = \frac{\sum_{i=1}^{n}((P_{i,t} * Y_{i,c} * S_{i,c,t}) - (C_c * S_{i,c,t}))}{ST_i} \quad (C19)$$

For the CHs, the actual gross margin is calculated as shown in Equation C20.

$$AGM_{i,t} = (HS_{i,actGrain} * (HP_{Grain} - HVC_{Grain})) + (HS_{i,actStover} * (HP_{Stover} - HVC_{Stover}) \quad (C20)$$

In Equation C20, $HS_{i,actGrain}$ is the actual harvested surface of corn grain by custom harvester i (ha), $HS_{i,actStover}$ is the actual harvested surface of corn stover by custom harvester i (ha), $HS_{maxGrain}$ is the maximum surface of corn grain that can harvested with one combine (ha), $HS_{maxStover}$ is the maximum surface of corn grain and stover that can harvested with the single pass harvester (ha), HP_{Grain} is the harvest price of corn grain (€/ha), HP_{Stover} is the harvest price of corn grain and stover (€/ha), HVC_{Grain} are the variable costs of harvesting corn grain and HVC_{Stover} are the variable costs of harvesting corn grain and stover.

Secondly, uncertainty (U_t) is calculated as shown in Equation C21, in which Y_{expt} is the agent's expected gross margin. Y_{expt} is calculated as is shown in Equation C22, in which DF is a discounting factor[23] randomly ranging between 0.2 and 0.8, and Y_{mean} is the mean of the actual gross margin of the other agents of the same agent type (i.e. farmers or CHs).

$$U_t = \frac{Y_t}{Y_{expt}} \qquad \text{(C20)}$$

$$Y_{expt} = Y_t^{1-\ DF} * Y_{mean}{}^{DF} \qquad \text{(C22)}$$

The combination of these two variables leads to four different behavioural rules that can be followed by the farmers and the CHs (Figure C.3 and Figure C.4). The first behavioural rule is repetition, applied by agents that are economically satisficed and certain about the decisions they make. Therefore, they are not inclined to make any changes to their behaviour. For the farmers, this means that they keep their current cropping plan. For the CHs, this means that they do not consider the option of investing in a new single-pass harvester. The second behavioural rule is imitation, applied by agents that are economically satisficed, but uncertain that their decisions are the best ones. Therefore, they will scan the behaviours in their close network and imitate the behaviour of the agent that performs best. Hence, imitating farmers will copy the cropping plant of the farmer with the highest actual gross margin in his close network. Imitating CHs will consider in purchasing a single-pass harvester if more than half of the CHs in their close network has invested in one. The third behaviour is social comparison, applied by economically unsatisfied agents uncertain about their decisions. These agents will look into their broad network in order to discover how they can improve their situation. Farmers will in this case copy the cropping plan of the farmer with the highest actual gross margin in their broad network. CHs will consider purchasing a single-pass harvester is more than half of the CHs in their broad network has invested in one. The fourth behaviour, deliberation, is the most economically rational behaviour and is applied by agents certain about their decisions but with a low economic satisfaction. Deliberating farmers will optimize their revenue by adjusting their cropping plan given the current crop prices (Equation C12 – C18).

Deliberating CHs will consider purchasing a single-pass harvester if the net present value (NPV) of their investment is positive. The net present value is calculated as shown in Equation C23 in which p is the discount rate equal to 0.07. In calculating this NPV, the custom harvester relies on the maximum number of hectares he could harvest yearly for a period of 12 years (Potential revenue).

[23] The discounting factor represents how much an agent takes into account the revenue gained by other agents of the same agent type.

$$NPV = \sum_{i}^{12} \frac{Potential\ revenue}{(1+p)^i} \tag{B23}$$

In all behaviours, CHs considering purchasing a single-pass harvester, will only invest if he is able to actually contract some hectares to harvest.

C.4.2.2. Connection farmers – processor procedure

In this procedure the farmers sell the corn stover directly to the manager of the cellulosic sugar production plant. In a first step, farmers calculate the minimum willingness to accept for the stover (WTA) (Equation C24). In this calculation, they take into account a declined corn grain yield in corn varieties of which the stover can be harvested. Furthermore, they take into account the additional harvest costs and the transportation costs to the cellulosic sugar production plant.

$$minWTA_i = \left(\left(Yield_{corn\ grain} - Yield_{corn\ grain\ (if\ stover)}\right) * \ P_{corn\ grain}\right) + \frac{HC_{corn\ stover}}{Yield_{corn\ stover}} + TC_{i,p} \tag{B24}$$

In Equation C24, $minWTA_i$ is the minimum willingness to accept of farmer i, expressed in €/ton DM, $Yield_{corn\ grain}$ (ton DM/ha) is the yield of corn grain when corn stover is not harvested (ton DM/ha), $Yield_{corn\ grain\ (if\ stover)}$ (ton DM/ha) is the yield of corn grain when both corn grain and stover is harvested, $P_{corn\ grain}$ (€/ton DM) is the price of corn grain, $HC_{corn\ stover}$ is the harvest cost of corn stover (€/ha), $Yield_{corn\ stover}$ is the yield of corn stover (ton DM/ha) and $TC_{i,p}$ is the transportation cost between farmer i and the cellulosic sugar production plant (€/ton DM). The transportation cost depends on the Eucledian distance between the two agents. The manager of the cellulosic production plant is assigned a maximum willingness to pay (WTP) at the start of the simulations. However, as he is not willing to offer his full maximum WTP, this value is adjusted using a compromising factor (Cr-factor).

$$Offer\ = Cr * maxWTP_j \tag{C25}$$

$$Cr = v^3 \tag{C26}$$

$$v = max[\frac{n}{N}, \frac{t}{T}] \tag{C27}$$

Next, the manager sends out this price offer to all farmers that want to and are able to sell their stover. The farmers accept the offer it is larger than their minimum WTA.

C.4.2.3. Connection custom harvesters – processor procedure

In this procedure, part of the request-for-purchase business model, the manager of the cellulosic sugar production plant and the CHs will first set up a contract with each other, before the CHs set up a contract with the farmers. Therefore, the manager sends out a price offer to the CHs, based on the maximum WTP. However, and similar to the previous procedure, the manager is not willing to offer the full max WTP. Therefore, this value is adjusted using a compromising factor (Cr-factor). This is explained in more detail below. The CHs that are interested to invest in a combined corn grain and stover harvester receive these offers, and calculate the NPV of their investment based on this offer (Equation C10). If the NPV is positive and the price offered is larger than the minimum WTA of the custom harvester, the custom harvester will accept the offer and set up a contract with the manager of the cellulosic sugar production plant. In calculating the minimum WTA, the CHs take into account the fact that they are responsible for the harvest and transportation costs, and the fact that they need to pay the farmers a certain price for their stover (Equation C28). The transportation cost depends on the Eucledian distance between the two agents.

$$minWTA_j = C_{fixed} + C_{variable} + P_{stover} + TC_{j,p} \quad \text{(B28)}$$

with $minWTA_j$ the minimum willingness to accept of custom harvester j (€/ton DM), C_{fixed} the single-pass harvester's fixed costs (€/ton DM), $C_{variable}$ the single-pass harvester's variable costs, P_{stover} the stover price expected by the custom harvester to be given to the farmers (€/ton DM) and $TC_{j,p}$ the average transportation costs between custom harvester j and the cellulosic sugar production plant (€/ton DM).

C.5. Results of the sensitivity analysis

C.5.1. Introduction

A sensitivity analysis was conducted on the effect of the aspiration level and the uncertainty value on the behaviour of both the farmers and the CHs. In analogy with (Jager et al. 2000), we did simulations for both farmers and CHs acting as *Homo Economicus* and *Homo Psychologicus*. The *Homo Economicus* can be considered as an economic rational actor, that is never satisfied nor uncertain. The *Homo Economicus* has therefore a high aspiration level and uncertainty value (average value of 0.95 (standard deviation (sd) 0.17)). The *Homo Psychologicus* is easily satisfied, but also very uncertain. The *Homo Psycholigicus* therefore has a low aspiration level and uncertainty value (average value of 0.05 (sd 0.17)).

C.5.2. Farmers acting as *Homo Economicus*

Below we discuss the results when farmers are acting as *Homo Economicus* (farmers have an average uncertainty value and aspiration level of 0.95) and compare them to the reference situation (farmers and CHs have an average uncertainty value and aspiration level of 0.5).

C.5.2.1. Share of interested and participating farmers

Figure C.11 shows, for each of the scenarios, the share of farmers interested to participate in the corn stover value chain (left) and the share of farmers actually participating (right). The share of interested farmers that act as *Homo Economicus* largely follows the same trend as in the reference scenario. However, the share is a lot higher. For the share of participating farmers, this is a lot higher in the bioprocessing coop scenario than in the reference situation. Concerning the stability of the share of interested and participating farmers, there is no large difference with the reference scenario: the direct sale and request-for-purchase scenarios show a more fluctuating pattern, while the supply coop and bioprocessing coop scenarios show a more stable pattern.

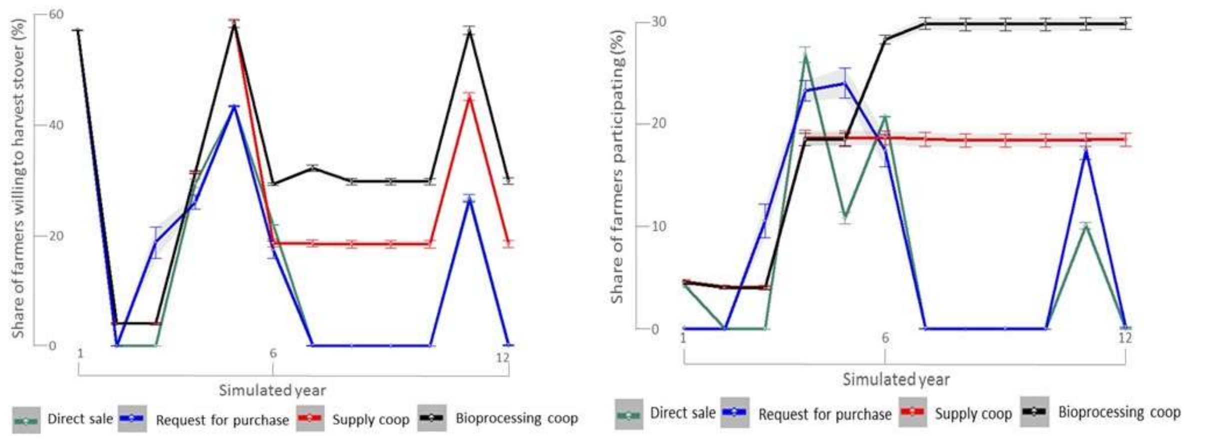


Figure C.11 Left: Share of farmers interested to participate in the corn stover value chain. Right: Share of farmers actually participating in the corn stover value chain for the four scenarios. The error bars and the grey ribbon represent the 95% confidence interval.

C.5.2.2. Number of custom harvesters owning a single-pass harvester

The left pane of Figure C.12 shows the share of CHs owning a single pass harvester, the right pane the number of single-pass harvesters in surplus given the surface of corn planted for the harvest of both grains and stover. Regarding the share of CHs owning a single-pass harvester, the overall trend is similar when farmers act as *Homo Economicus* or in the reference situation. However, compared to the reference situation, we see that a lot more CHs purchase a single-pass harvester in the bioprocessing coop scenario. This also explains the higher share of participating farmers in this scenario compared to the reference situation. Regarding the number of machines in surplus, also these graphs follow the same trend as in the reference situation, with a very large number of machines in surplus for the direct sale and request-for-purchase scenarios, and a very limited number of machines in surplus for both the cooperative scenarios. These results confirm our findings of the central, but vulnerable position of the CHs in the value chain.

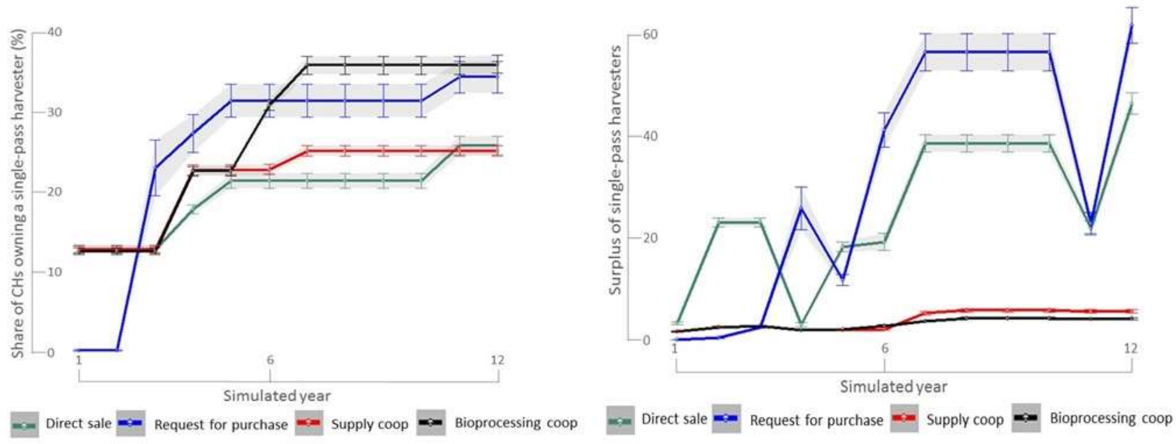


Figure C.12 Left: Share of CHs owning a single-pass harvester for the four scenarios (%). Right: Actual number of machines in surplus for the surface of corn planted for the harvest of both grains and stover for the four scenarios. The error bars and the grey ribbon represent the 95% confidence interval.

C.5.2.3. Production capacity of the cellulosic sugar production plant (CSPP)

Figure C.13 shows the volume of corn stover purchased by the manager of the CSPP as a percentage of the maximum processing capacity of the plant (250,000 ton DM). The same observations are made as in the reference situation: a largely fluctuating stover supply for the direct sale and request-for-purchase scenarios and a stable supply for both cooperative scenarios. When farmers act as *Homo Economicus,* the supply in the bioprocessing scenario is a lot higher than in the reference situation. However, the CSPP manager is also in this case never able to purchase enough stover to operate at full capacity.

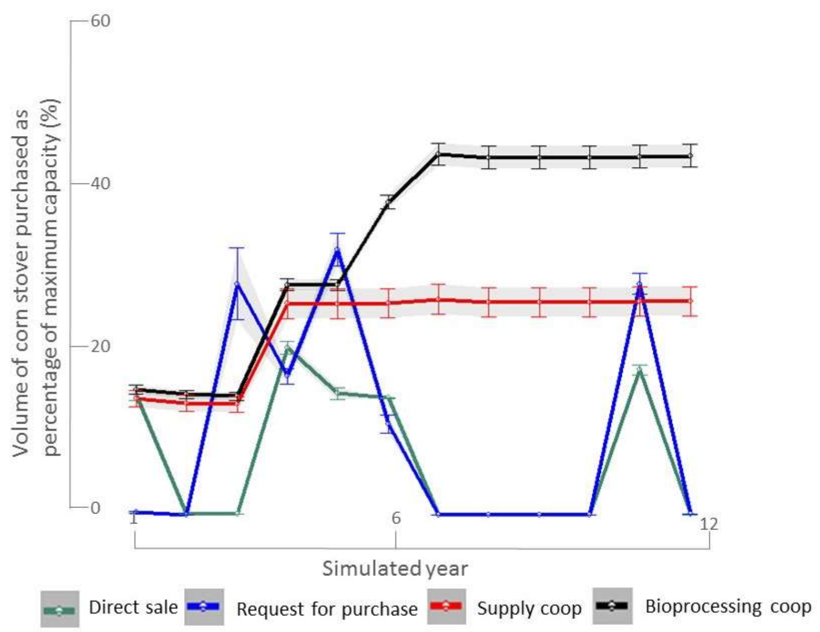


Figure C.13 Volume of corn stover purchased by the manager of the CSPP as a percentage of the maximum processing capacity for the four governance structures simulated. The error bars and the grey ribbon represent the 95% confidence interval.

C.5.3. Farmers acting as Homo Psychologicus

Below we discuss the results when farmers are acting as *Homo Psychologicus* (farmers have an average uncertainty value and aspiration level of 0.05) and compare them to the reference situation (farmers and CHs have an average uncertainty value and aspiration level of 0.5).

C.5.3.1. Share of interested and participating farmers

Figure C.14 shows, for each of the scenarios, the share of farmers interested to participate in the corn stover value chain (left) and the share of farmers actually participating (right). The share of interested farmers that act as *Homo Psychologicus* largely follows the same trend as in the reference scenario. For the share of participating farmers, this is a lot lower in all scenarios compared to the reference situation. Concerning the stability of the share of interested and participating farmers, there is no large difference with the reference scenario: the direct sale and request-for-purchase scenarios show a more fluctuating pattern, while the supply coop and bioprocessing coop scenarios show a more stable pattern.

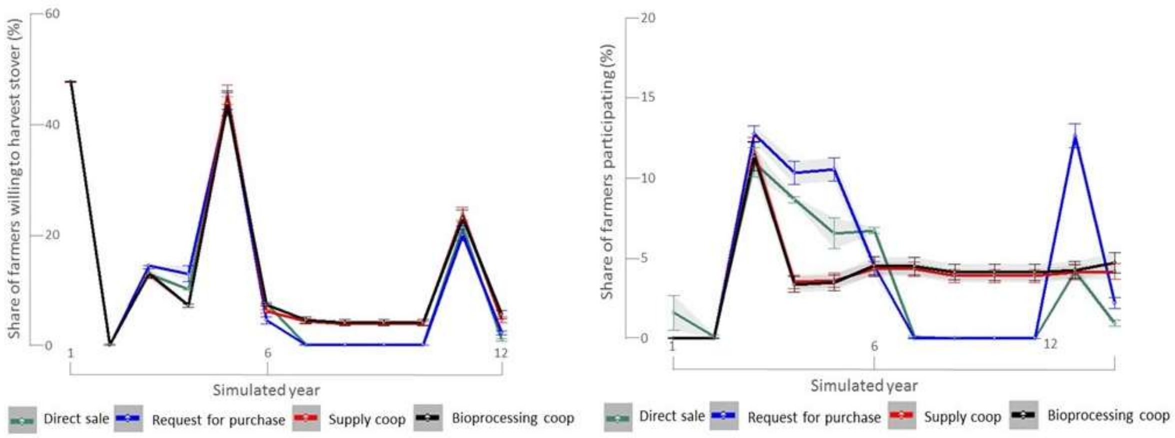


Figure C.14 Left: Share of farmers interested to participate in the corn stover value chain. Right: Share of farmers actually participating in the corn stover value chain for the four scenarios. The error bars and the grey ribbon represent the 95% confidence interval.

C.5.3.2. Number of custom harvesters owning a single-pass harvester

The left pane of Figure C.15 shows the share of CHs owning a single pass harvester, the right pane the number of single-pass harvesters in surplus given the surface of corn planted for the harvest of both grains and stover. Regarding the share of CHs owning a single-pass harvester, the overall trend is similar when farmers act as *Homo Psychologicus* or in the reference situation. However, compared to the reference situation, we see that a lot less CHs purchase a single-pass harvester in all scenarios. This also explains the lower share of participating farmers compared to the reference situation. Furthermore, the confidence intervals of the results are a lot wider. Regarding the number of machines in surplus, also these graphs follow the same trend as in the reference situation, with a very large number of machines in surplus for the direct sale and request-for-purchase scenarios, and a more limited number of machines in surplus for both the cooperative scenarios. These results confirm our findings of the central, but vulnerable position of the CHs in the value chain.

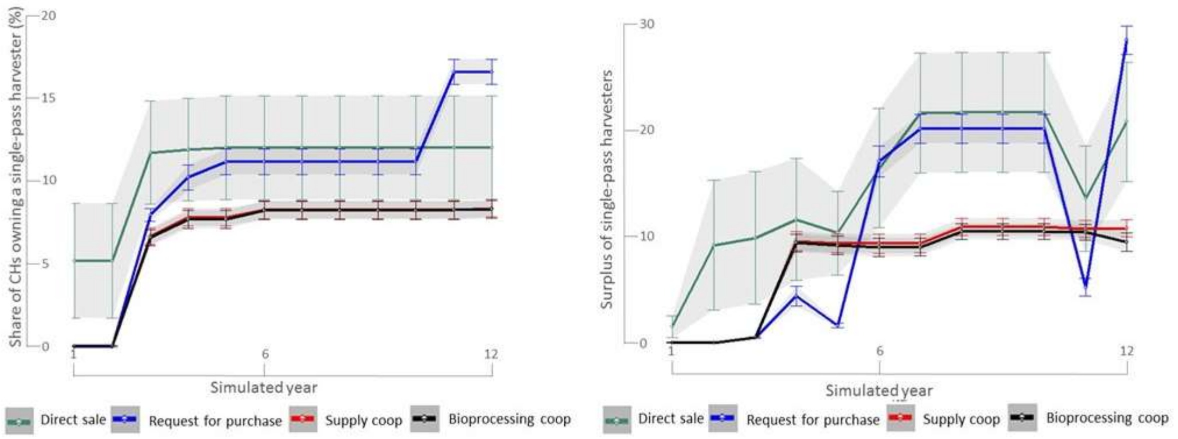


Figure C.15 Left: Share of CHs owning a single-pass harvester for the four scenarios (%). Right: Actual number of machines in surplus for the surface of corn planted for the harvest of both grains and stover for the four scenarios. The error bars and the grey ribbon represent the 95% confidence interval.

C.5.3.3. Production capacity of the cellulosic sugar production plant (CSPP)

Figure C.16 shows the volume of corn stover purchased by the manager of the CSPP as a percentage of the maximum processing capacity of the plant (250,000 ton DM). The same observations are made as in the reference situation: a largely fluctuating stover supply for the direct sale and request-for-purchase scenarios and a stable supply for both cooperative scenarios. Additionally, when farmers act as *Homo Psychologicus,* the supply to the CSPP remains limited to 20% of its maximum capacity.

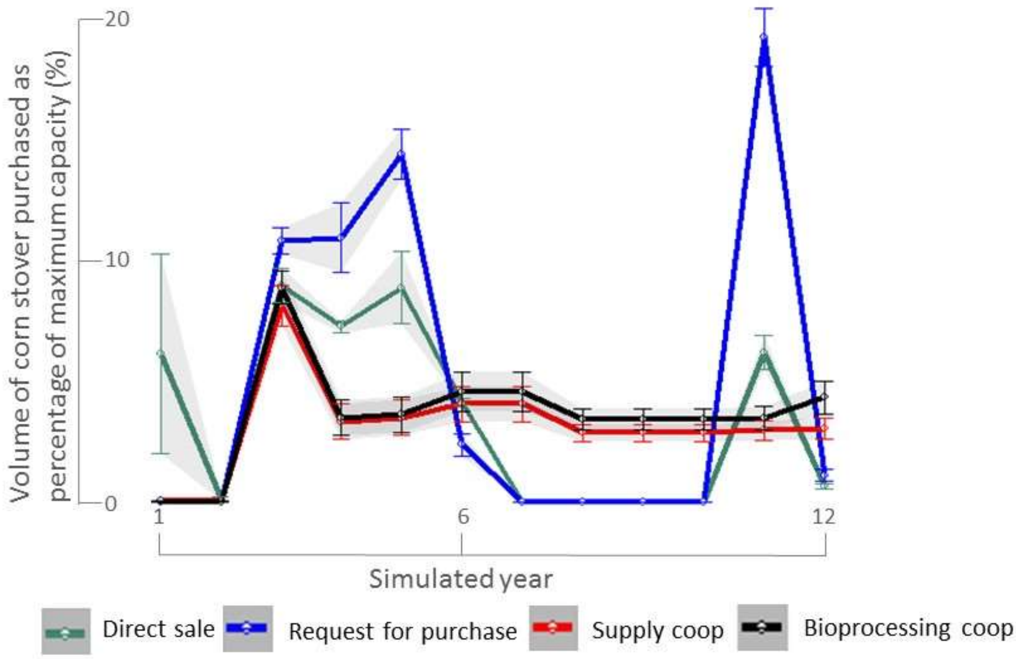


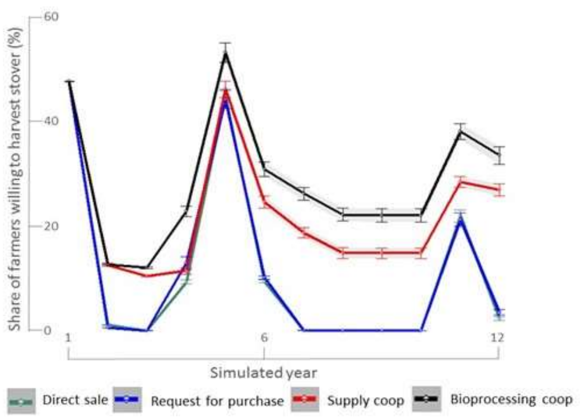
Figure C.16 Volume of corn stover purchased by the manager of the CSPP as a percentage of the maximum processing capacity for the four governance structures simulated. The error bars and the grey ribbon represent the 95% confidence interval.

C.5.4. Custom harvesters acting as Homo Economicus

Below we discuss the results when CHs are acting as *Homo Economicus* (CHs have an average uncertainty value and aspiration level of 0.95) and compare them to the reference situation (farmers and CHs have an average uncertainty value and aspiration level of 0.5).

C.5.4.1.Share of interested and participating farmers

Figure C.17 shows, for each of the scenarios, the share of farmers interested to participate in the corn stover value chain (left) and the share of farmers actually participating (right). The share of interested farmers when CHs act as *Homo Economicus* largely follows the same trend as in the reference scenario. For the share of participating farmers, this is similar to the reference situation for the direct sale and request-for-purchase scenarios. However, the share of participating farmers in both cooperative scenarios is a lot higher when CHs act as *Homo Economicus* compared to the reference situation. Concerning the stability of the share of interested and participating farmers, there is no large difference with the reference scenario: the direct sale and request-for-purchase scenarios show a more fluctuating pattern, while the supply coop and bioprocessing coop scenarios show a more stable pattern.



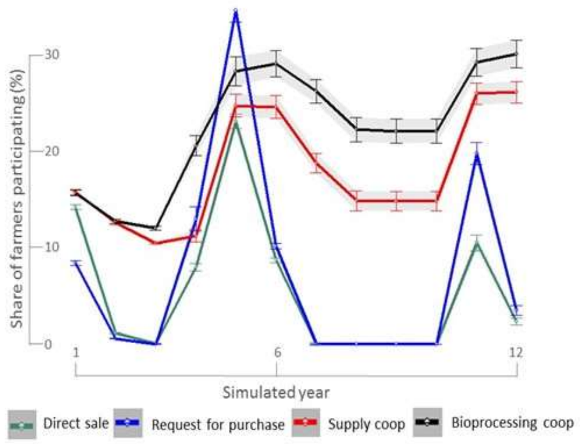


Figure C.17 Left: Share of farmers interested to participate in the corn stover value chain. Right: Share of farmers actually participating in the corn stover value chain for the four scenarios. The error bars and the grey ribbon represent the 95% confidence interval.

C.5.4.2. Number of custom harvesters owning a single-pass harvester

The left pane of Figure C.18 shows the share of CHs owning a single pass harvester, the right pane the number of single-pass harvesters in surplus given the surface of corn planted for the harvest of both grains and stover. Regarding the share of CHs owning a single-pass harvester, this number is a lot higher when CHs act as *Homo Economicus* compared to the reference situation, especially for the two cooperative scenarios. This also explains the higher share of participating farmers compared to the reference situation in these two scenarios. Regarding the number of machines in surplus, the number of single-pass harvesters in surplus is a lot higher when CHs act as *Homo Economicus* compared to the reference situation. This is true for all scenarios, however, the difference more striking for the two cooperative scenarios. Furthermore, the graphs follow the same trend as in the reference situation. These results confirm our findings of the central, but vulnerable position of the CHs in the value chain.

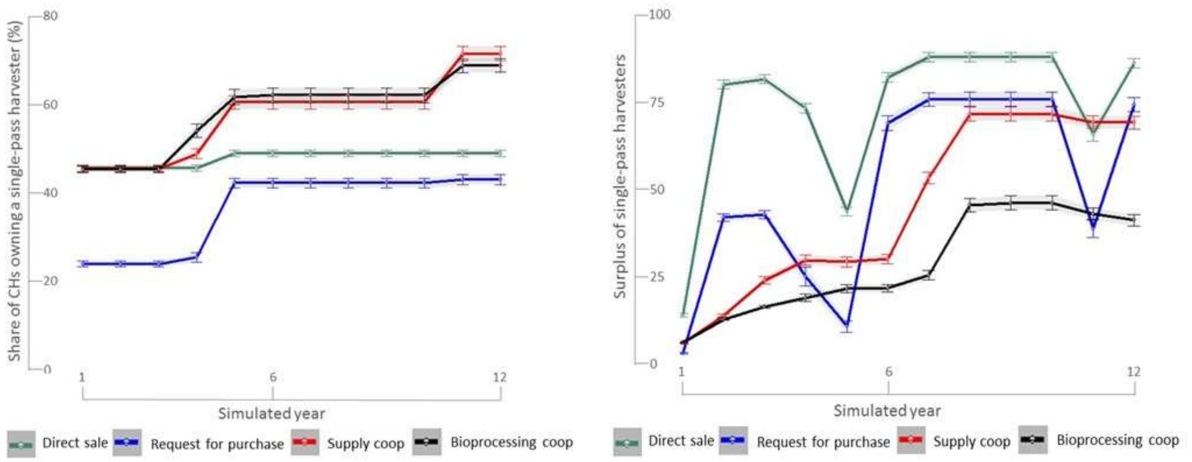


Figure C.18 Left: Share of CHs owning a single-pass harvester for the four scenarios (%). Right: Actual number of machines in surplus for the surface of corn planted for the harvest of both grains and stover for the four scenarios. The error bars and the grey ribbon represent the 95% confidence interval.

C.5.4.3. Production capacity of the cellulosic sugar production plant (CSPP)

Figure C.19 shows the volume of corn stover purchased by the manager of the CSPP as a percentage of the maximum processing capacity of the plant (250,000 ton DM). The same observations are made as in the reference situation: a largely fluctuating stover supply for the direct sale and request-for-purchase scenarios. In the cooperative scenarios, the stover supply is less stable when CHs act as *Homo Economicus* compared to the reference situation. However, it remains far more stable than in the other two scenarios. Additionally, when CHs act as *Homo Economicus,* the supply to the CSPP is a lot higher compared to the reference scenario. Especially in the bioprocessing scenario, the supply mounts to about 70% of the CSPP's maximum capacity. This can be attributed to the higher number of participating farmers, thanks to the higher number of single-pass harvesters in the supply chain. However, in none of the scenarios, the CSPP manager can purchase sufficient stover to operate at full capacity.

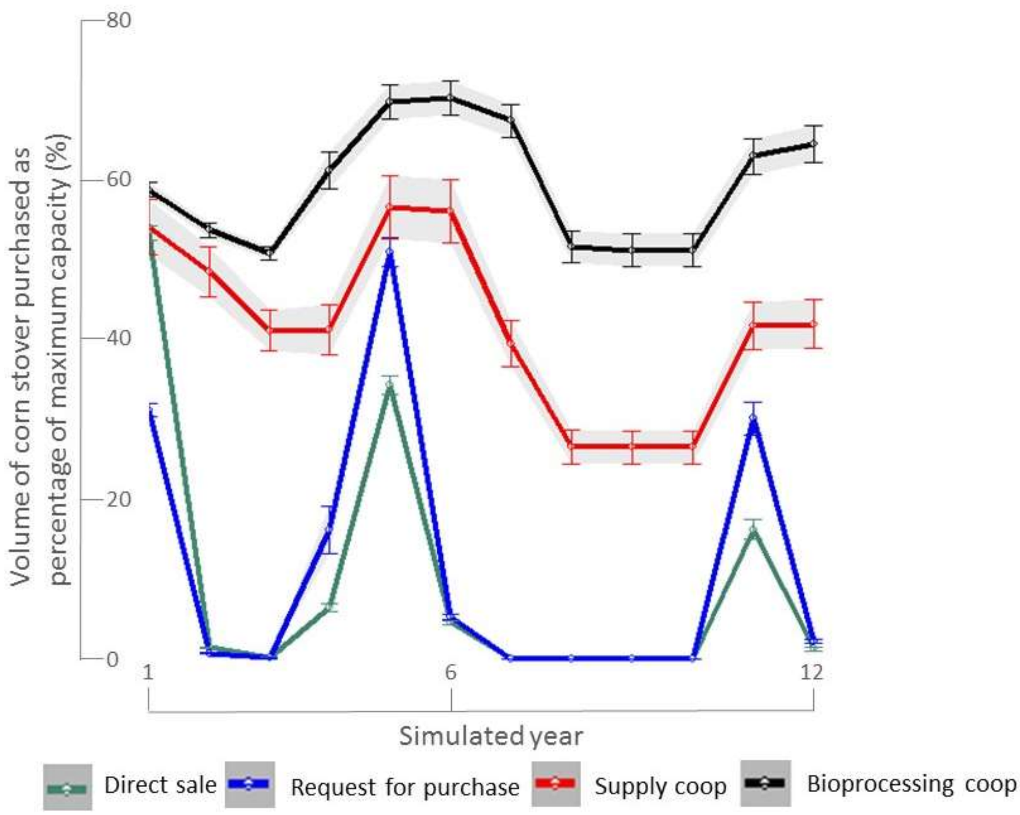


Figure C.19 Volume of corn stover purchased by the manager of the CSPP as a percentage of the maximum processing capacity for the four governance structures simulated. The error bars and the grey ribbon represent the 95% confidence interval.

C.5.5. Custom harvesters acting as *Homo Psychologicus*

Below we discuss the results when CHs are acting as *Homo Psychologicus* (CHs have an average uncertainty value and aspiration level of 0.05) and compare them to the reference situation (farmers and CHs have an average uncertainty value and aspiration level of 0.5).

C.5.5.1. Share of interested and participating farmers

Figure C.20 shows, for each of the scenarios, the share of farmers interested to participate in the corn stover value chain (left) and the share of farmers actually participating (right). The share of interested farmers when CHs act as *Homo Psychologicus* largely follows the same trend as in the reference scenario. For the share of participating farmers, the trend is similar to the reference situation for all scenarios. However, the share of participating farmers in both cooperative scenarios is a lot lower when CHs act as *Homo Psychologicus* compared to the reference situation. Concerning the stability of the share of interested and participating farmers, there is no large difference with the reference scenario: the direct sale and request-for-purchase scenarios show a more fluctuating pattern, while the supply coop and bioprocessing coop scenarios show a more stable pattern.

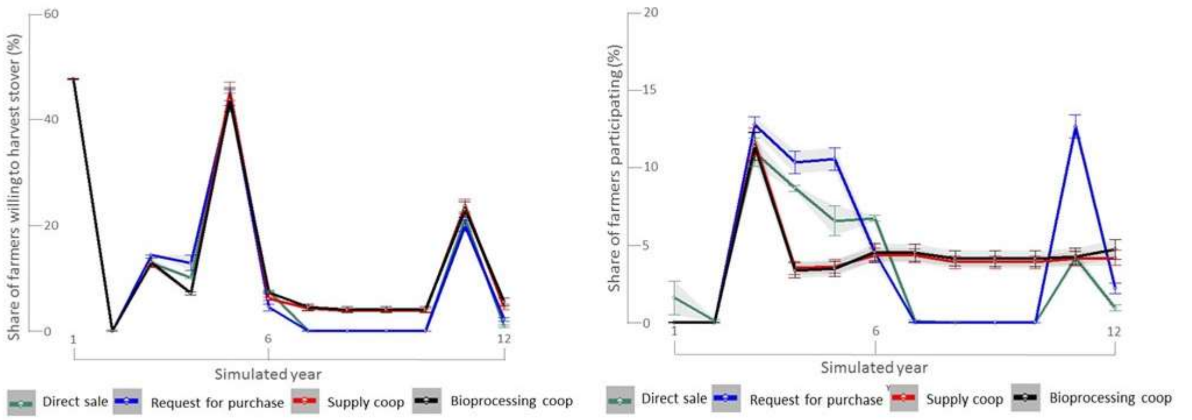


Figure C.20 Left: Share of farmers interested to participate in the corn stover value chain. Right: Share of farmers actually participating in the corn stover value chain for the four scenarios. The error bars and the grey ribbon represent the 95% confidence interval.

C.5.5.2. Number of custom harvesters owning a single-pass harvester

The left pane of Figure C.21 shows the share of CHs owning a single pass harvester, the right pane the number of single-pass harvesters in surplus given the surface of corn planted for the harvest of both grains and stover. Regarding the share of CHs owning a single-pass harvester, this number is a lot lower when CHs act as *Homo Psychologicus* compared to the reference situation. This also explains the lower share of participating farmers compared to the reference situation. Regarding the number of machines in surplus, also these graphs follow the same trend as in the reference situation, with a very large number of machines in surplus for the direct sale and request-for-purchase scenarios, and a more limited number of machines in surplus for both the cooperative scenarios. These results confirm our findings of the central, but vulnerable position of the CHs in the value chain.

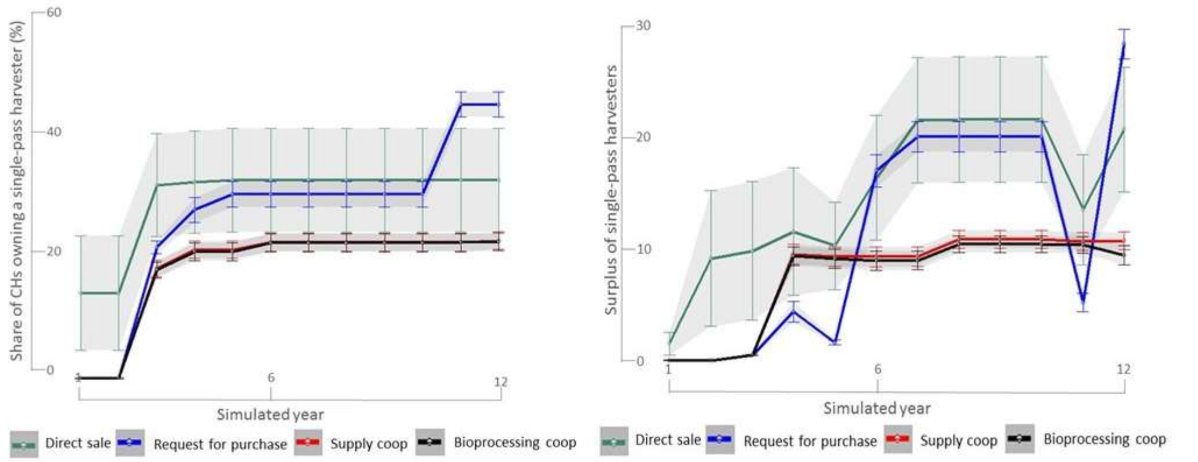


Figure C.21 Left: Share of CHs owning a single-pass harvester for the four scenarios (%). Right: Actual number of machines in surplus for the surface of corn planted for the harvest of both grains and stover for the four scenarios. The error bars and the grey ribbon represent the 95% confidence interval.

C.5.5.3. Production capacity of the cellulosic sugar production plant (CSPP)

Figure C.22 shows the volume of corn stover purchased by the manager of the CSPP as a percentage of the maximum processing capacity of the plant (250,000 ton DM). The same observations are made as in the reference situation: a largely fluctuating stover supply for the direct sale and request-for-purchase scenarios. Additionally, when CHs act as *Homo Psychologicus,* the supply to the CSPP is a lot lower compared to the reference scenario, and remains limited to about 20% of the CSPP's maximum capacity. This can be attributed to the lower number of participating farmers, due to the lowernumber of single-pass harvesters in the supply chain. Hence, in none of the scenarios, the CSPP manager can purchase sufficient stover to operate at full capacity.

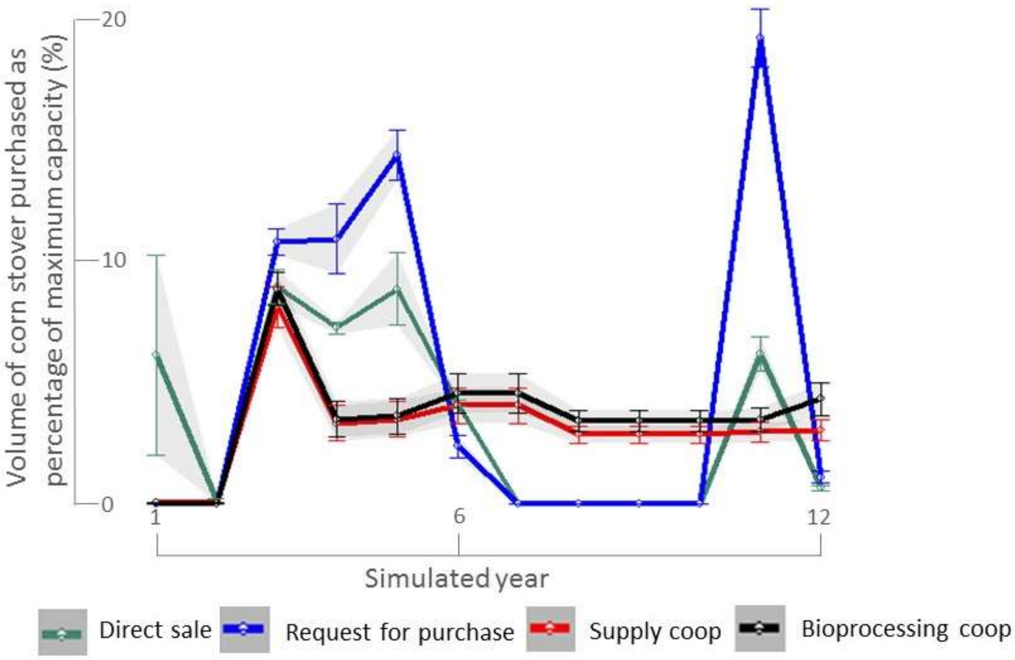


Figure C.22 Volume of corn stover purchased by the manager of the CSPP as a percentage of the maximum processing capacity for the four governance structures simulated. The error bars represent the 95% confidence interval.

C.5.6. Discussion of the results of the sensitivity analysis and conclusion

Overall, we found similar trends in the results whether farmers or CHs act as *Homo Economicus* or *Homo Psychologicus*. Therefore, the results of the sensitivity analysis confirm our main findings, being that:

- the CSPP manager can never purchase sufficient stover to operate at maximum capacity,
- the central but vulnerable position of the CHs in the value chain, and

- the more stable farmers' participation rate in case of a cooperative governance structure compared to a direct sale or request-for-purchase scenario.

In general the results indicate that if either the farmers or the CHs act as *Homo Economicus,* farmers' participation rate is higher, more CHs invest in a single pass harvester and stover supply to the CSPP is larger. Conversely, if either the farmers or the CHs act as *Homo Psychologicus*, farmers' participation rate tends to be lower, less CHs invest in a single pass harvester and stover supply to the CSPP remains very limited.

Annex D: From semi-structured interviews to agent-based model

D.1. Introduction

At several places throughout this dissertation, we referenced to the use of a mixed-method approach, integrating semi-structured interviews and agent-based modelling. In this annex, we elaborate more on this mixed-method approach, and more specifically, on one aspect, namely how the results of the semi-structured interviews were used to construct an agent-based model. Therefore, in the following section, we elaborate on the meaning of “mixed-method approach”. Next, we discuss for the case studies presented in chapters 2, 3, and 4 how we went from qualitative research to semi-structured interviews. In the final section, we present a more general and step-wise “roadmap”, which will could be useful for researchers interested in using the same approach.

D.2. Mixed-method approach

In this dissertation, we define a mixed-method approach as a research approach in which qualitative and quantitative research methods are integrated. The word “integrated” in this definition means that the results of the qualitative method and the quantitative method are not only placed next to each other for comparison. Instead, the interplay between the results is the focus of using a mixed-method approach. According to Pluye and Hong (2014), a mixed-method approach is advantageous, as it “combines the strengths of the quantitative and qualitative methods and compensates for their respective limitations”. In this dissertation, we specifically integrated the insights from semi-structured interviews (qualitative research method) with the simulation results from agent-based models (quantitative research method). More concretely, we used a sequential exploratory mixed-method design (Pluye & Hong 2014), meaning that we first conducted and analysed the semi-structured interviews to feed the agent-based models. Then, the results of the agent-based models were interpreted, which further helped to understand and confirm the findings from the semi-structured interviews.

In the remainder of this annex, we focus on the first part and detail how we conducted and analysed the semi-structured interviews and how these insights were used to develop the agent-based models presented in chapters 2, 3 and 4.

D.3. From semi-structured interviews to agent-based model

D.3.1. Semi-structured interviews

D.3.1.1. Selection of the respondents

The first step of developing the agent-based models, presented in chapters 2, 3 and 4 of the dissertation, was the selection of the respondents for the semi-structured interviews. They were identified and selected through snowball sampling. This means that when interviewees referred to other relevant stakeholders during the interview, they were interviewed as well (Patton 1990). The first interviews were held with experts, which were identified through a web search and selected based on the organisation they represented and their specific knowledge on the subject. These experts were for example farmer advisors, researchers, representatives of farm organisations, etc. Besides providing general insights into the subject that was investigated, these experts also provided names of other experts and practitioners, including farmers, owners of biogas plants, custom harvesters. These stakeholders, in turn, provided names of new stakeholders. Interviews with these respondents provided more detailed and practical knowledge. When no new information or names of relevant stakeholders appeared, the point of saturation was achieved (Morse 1991) and the interview round ended.

D.3.1.2. Interview guide

Specific to the use of semi-structured interviews is the development of an interview guide. We developed an interview guide for each case study, namely the silage maize market and the potential of a corn stover value chain in Flanders. As such, we prevented to forget important topics. However, we kept the freedom of going deeper into a particular topic and ask additional questions when this was considered interesting to better understand the case study. In practice, we kept the main structure of the interview guide for each respondent, but we made adjustments based on the “type” of respondent, as we believed they could provide a different kind of information. For example, although the topics remained the same, slightly different questions were asked to researchers or representatives of farm organisations, than for example to the farmers, biogas plant owners, representatives from industry or policy makers, etc.

For the case study presented in chapter 2, questions asked to the different respondents merely focussed on: the different factors that influenced whether farmers would sell or buy silage maize; the regional differences in silage maize quality, price, etc.; description of the relationships between farmers; description of the formal and informal agreements made between farmers when trading silage maize. Questions asked to farmers and biogas plant managers were more focused on the practical side of the silage maize trade and more anecdotal information was asked. For example: “When was the last time you sold or bought silage maize? Could you give some details on the agreement that was made, the price, etc.”; or “How do you decide which feedstock and which volumes of each feedstock you will use in your biogas plant?”.

For the case study presented in chapters 3 and 4, questions merely focussed on the potential advantages and disadvantages of corn stover harvest in general, the advantages and disadvantages of the different harvest techniques, the potential use of corn stover in different valorisation trajectories, etc. Examples of questions are: “According to you, can corn stover harvest be beneficial / disadvantageous, and why?”, or “When was the last time you invested in a new harvest machine? Could you tell us more why you chose that particular machine?”.

For interested readers, the full interview guides are available (in Dutch) upon request (anouk.mertens@ilvo.vlaanderen.be).

D.3.1.3. Analysis of the interviews

All interviews were recorded and fully transcribed. This allowed us to transcribe the data and analyse it in NVIVO 11 software using thematic analysis (Vaismoradi et al. 2013). Selecting the different themes, also referred to as coding, was an iterative process, in which we went through the interviews several times, before we selected the final themes.

For the case study presented in chapter 2, following themes and subthemes were selected:

- Durable relationships
- Evolution in market
- Formal contracts
- Local rootedness
- Relational governance
    - Societal culture
        - Flexibility
        - Information exchange
        - Mutual understanding or common norms, values and visions
            - Long term gains over short term gains
            - Reputational capital
            - Require history of interaction
        - Reluctance
            - Long term contracts
            - New developments (biogas plants)
        - Solidarity
    - Trust
        - Growing over time

For the case study presented in chapters 3 and 4, following themes and subthemes were selected:

- Agricultural contractors
    - Availability
    - Competition
    - Investment
- Corn varieties
- Economic considerations
    - Buying price for processors
    - Efficiency and economic viability
    - Yield
    - Selling price for farmers
- Motivation for corn stover harvest and processing

    - Advantages
    - Disadvantages
        - SOC and soil structure
            - Alternatives
                - Biochar
                - Compost
                - Manure
            - Debate silage maize and removal corn stover
        - Erosion
        - Nutrients
        - Weather and wet field conditions
            - Tracks on machines
- Remarks on model
- Harvest method
    - Multiple pass
        - Advantages
        - Cob harvesting
        - Disadvantages
            - Dirty because of earth and mud
            - Effect on soil
            - Leave a lot of stover on the field
    - Single pass
        - Advantages
            - No problems with earth and mud
        - Disadvantages
            - Heavy machine
            - Investment cost
            - Large size of machine
                - Fields
                - Roads
- Innovation process
    - Similar innovations
- Potential policy measures
- Storage
    - Bales
    - Drying
    - Ensiling
    - Pellets
    - Stover too wet for storage
- Transportation
- Valorisation trajectory
    - Anaerobic digestion
    - Animal bedding
    - Bio-ethanol
    - Burning
    - Feed
    - Fibre boards
    - Isolation
    - Mushroom farming
    - Only cob valorisation
    - Paper and cardboard
    - Potting soil
    - SOC and improvement of soil

Sorting the information from the interview under these themes, allowed us to better understand what the stakeholders were generally saying about a given subject, and therefore gain a more structured insight into the respective case study.

Besides determining these themes, the analysis also allowed us to identify the actors that were most influential to the silage maize and corn stover value chains. For the silage maize value chain, these were dairy farmers and biogas plant managers. Furthermore, we found a clear distinction between farmers with a silage maize surplus and farmers with a silage maize deficit. This is explained further in Box 1. In this

For the corn stover value chain, these were farmers, custom harvesters, and potential corn stover processors, namely biogas plant operators and a manager of a large-scale processing facility. During the interviews on the corn stover value chain, respondents indicated a clear preference for the valorisation of the corn stover into a high value product. Therefore, we chose to focus on the processing of corn stover into cellulosic sugars.

D.3.2. Conceptual model development

We used the narrative data from the semi-structured interviews to construct the agent-based models. A first step is to develop a conceptual model, schematically describing the relationships between the different actors, as well as their possible actions. Again, the development of a conceptual model is done step by step, parallel to the semi-structured interviews. Indeed, as the interviews increasingly provide understanding of the value chain and the mechanisms at play, the complexity of the conceptual model also gradually increases. For the case study presented in chapter 2, this resulted in the conceptual models presented in Figure 2.2 and Figure A.3. For the case study presented in chapters 3 and 4, this resulted in Figure 3.1 and Figure B.3 and Figure 4.1 and Figure C.5, respectively. These conceptual models gave us a first structure of how the agent-based model should look like, and which procedures and behavioural rules should be integrated.

D.3.3. From conceptual model to model code

The behavioural rules, relationships and procedures integrated in the conceptual models needed to be translated into modelling code. More specifically, they needed to be converted to equations and algorithms. We used literature information for the conversion. For the model presented in chapter 2, on the silage maize market, we relied on previous work conducted by Klos and Nooteboom (2001) in how to model trust relationships. For the research on corn stover value chain development, we relied on the work of Jager (2000), who introduced the consumat approach as a meta-model of different expert-theories of human behaviour (Jager *et al.* 2000), and van Duinen et al. (2016), who applied this approach in a more practical and agricultural context.

Similar to the previous steps described, the translation from conceptual model to coded model was an iterative process, in which first simple versions of the model were constructed and tested, and model complexity was gradually increased. Different versions of the model with increasing complexity were retained.

D.3.4. Model validation

Whenever we had the opportunity, we presented the model and its result to various researchers, including agricultural economists, but also agent-based modelling experts, and at different conferences. When questions were asked or comments were made, we tried to take them into account as much as possible. Regarding the model developed for chapter 2, we only presented the model to experts that were not interviewed before. Regarding the models developed for chapters 3 and 4, we presented the models and their results both to researchers and experts who were not interviewed before, and to those who were interviewed before. Indeed, as explained in the dissertation, a corn stover value chain is virtually non-existent in Flanders, forcing stakeholders to rely merely on assumptions rather than on their own experiences. This constrained attempts to gain a thorough and in-depth understanding of the possible organisational challenges. Therefore, in order to validate our insights from the model and the subsequent translation into an agent-based model, we organised a workshop to which we invited several of the stakeholders interviewed and some additional ones. These stakeholders were researchers, representatives from farmers organisations, custom harvester representatives, policy makers etc. During this workshop, the attendants made some comments to the model, which we further integrated in the model.

D.4. General procedure to be applied in future research

The mixed-methodology approach followed in this research, and more specifically the first step of the use of insights gained from semi-structured interviews to guide the development of agent-based models, can be summarized as follows:

Step 1: Selection of respondents for semi-structured interviews through snowball sampling;

Step 2: Conducting semi-structured interviews using an interview guide. The interviews should be recorded;

Step 3: Transcription of the interviews;

Step 4: Iterative analysis of the interviews using thematic analysis method;

Step 5: Identification of the main agents involved in the value chain, their relationships and their main behavioural rules;

Step 6: Developing the conceptual model, schematically presenting how the main agents involved in the value chain are related to each other and their behavioural rules, and translating the findings of the semi-structured interviews in different procedures;

Step 7: Iteratively translating the conceptual model into model code, whereby different models with increasing model complexity are developed and tested; and

Step 8: Presenting the model and its preliminary results as much as possible to the different stakeholders at various occasions, including conferences, workshops, etc., in order to be able to acquire feedback on the model and its results and have the chance to further improve the model. In case of a new value chain, making reflection by the stakeholders individually is difficult. Therefore, we advise to organise an additional workshop with multiple stakeholders involved, specifically with the aim of validating the insights gained from the interviews and the translation of the model into code, as well as validating the modelling results.

Curriculum Vitae

Anouk Mertens was born in Antwerpen (Belgium) on April 19th 1988. In 2011, she graduated with a master in Bio-science Engineering, specialization 'Tropical Natural Resources Management', from the Catholic University of Leuven. She then enrolled in the "*Master en Science et Gestion de l'Environnement*" at the Catholic University of Leuven in Louvain-la-Neuve, from which she graduated in 2013. During her studies, she did a 2 months internship at the United Nations Development Programme, Small Grants Programme, and a 6 months internship at the United Nations Environment Programme, both in Samoa. In 2013, she started her PhD study at Ghent University in collaboration with the Social Sciences Unit of ILVO. Also in 2013, she applied successfully for an IWT doctoral (PhD) grant for strategic basic research. Anouk attended various national and international conferences and is also the (co-)author of several research articles, of which one is published and 3 are in review in international peer reviewed journals.

Peer reviewed publication

Mertens, A., Van Meensel,J., Mondelaers, K., Lauwers, L., Buysse, J. (2016) Context matters – Using an agent-based model to investigate the influence of market context on the supply of local biomass for anaerobic digestion. Bioenergy Research, 9 (1): 132-145

Articles currently under review

Mertens, A., Van Meensel, J. Willem, L., Lauwers, L., Buysse, J. (2017) Governance structures and their impact on the development of a corn stover value chain in Flanders.

Publication in scientific journal without peer-review

Mertens, A., Van Meensel, J., Buysse, J. (2015) Context matters: the importance of market characteristics in the volatility of feedstock costs for biogas plants. Communications in Agricultural an Applied Biological Sciences, 80: 23-28.

Mertens, A., Van Meensel, J., Willem, L., Buysse, J. (2016). Can resource competition encourage market development? A case study on the development of a corn stover market in Flanders. Proceedins of the 24th European Biomass Conference and Exhibition, Amsterdam: 1431-1440

Conference participation with oral or poster presentations

Mertens, A., Mondelaers, K., Claeys, D., Lauwers, L., Buysse, J. (2014). Unravelling the informal silage maize trade market: A multi-agent modelling approach. Short paper presentation at the 15th PhD Symposium Agricultural and Natural Resource Economics. April 30 2014, Brussels, Belgium.

Mertens, A., Mondelaers, K., Claeys, D., Lauwers, L., Buysse, J. (2014). Unravelling the informal silage maize trade: a multi-agent modelling approach. Poster presentation at the EAAE 2014 Congress "Agri-Food and Rural Innovations for Healthier Societies". August 26-29 2014, Ljubljana, Slovenia.

Mertens, A., Van Meensel, J., Mondelaers, K., Buysse, J. (2015). Context matters: The importance of market characteristics in the volatility of feedstock costs for biogas plants. Paper presentation at the 20th National Sympsium for Applied Biological Sciences. January 30 2015, Louvain-la-Neuve, Belgium

Mertens, A., Van Meensel, J., Buysse, J. (2015). Give competitors a helping hand or throw a spanner in the works? An agent-based model simulating the development of a corn stover market in Flanders. Short paper presentation at the 16th PhD Symposium Agricultural and Natural Resource Economics. April 29 2016, Brussels, Belgium.

Mertens, A., Van Meensel, J., Buysse, J. (2015). Give competitors a helping hand or throw a spanner in the works? A case study for the development of a corn stover market in Flanders. Paper presentation at the 6th EAAE PhD Workshop, June 8-10 2015, Rome, Italy

Mertens, A., Van Meensel, J., Buysse, J. (2015). Exploring the potentials of a corn stover market under the promotion of different valorisation techniques – An agent-based model. Paper presentation at the European Social Simulation Association Conference, September 14-18 2015, Groningen, Netherlands.

Mertens, A., Van Meensel, J., Willem, L., Buysse, J. (2016). The influence of different business models on the performance of the maize stover market. Short paper presentation at the 17th PhD Symposium Agricultural and Natural Resource Economics. March 11 2016, Antwerp, Belgium.

Mertens, A., Van Meensel, J., Willem, L., Buysse, J. (2016). The influence of governance structure on the development of new biorefinery value chain. Paper presented at the 12th International Conference on Renewable Resources & Biorefineries, May 30 – June 1 2016, Ghent, Belgium

Mertens, A., Van Meensel, J. Willem, L., Buysse, J. (2016). Can resource competition encourage market development? A case study on the development of a corn stover market in Flanders. Poster presentation at the 24th European Biomass Conference & Exhibition, June 6-9, Amsterdam, Netherlands.

Mertens, A., Van Meensel, J., Willem, L., Buysse J. (2016). The importance of governance structure for the development of a corn stover value chain. Paper presentation at the European Social Simulation Association Conference, September 19-23 2016, Rome, Italy. Presentation done by Klaas Sys.

Mertens, A, Van Meensel, J., Mondelaers, K., Lauwers, L., Buysse, J. (2016). Context matters – Using an agent-based model to investigate the influence of market context on the supply of local biomass for anaerobic digestion. Poster presented at the European Biogas Association Conference, September 27-29 2016, Ghent, Belgium

Various

Best Presentation Award – National Symposium for Applied Biological Sciences (Louvain-la-Neuve): 30/01/2015

Organisation of 1st ESSA PhD Colloquium, September 19 2016, Rome, Italy.