



The interaction between an industry
revitalised through Industrial Symbiosis
and its local workforce

*A socially aware exploratory agent-based model of the
sugar industry in Norte Fluminense, Brazil*

Frederique de Groen

The interaction between an industry revitalised through Industrial Symbiosis and its local workforce

A socially aware exploratory agent-based model of the sugar industry in Norte Fluminense, Brazil

by

Frederique de Groen

to obtain the degree of Master of Science
at the Delft University of Technology and Leiden University,
to be defended publicly on Thursday March 22, 2018 at 13:00.

Student number: Delft 4196228 – Leiden s1776991
Project duration: September 19, 2017 – March 22, 2018
Thesis committee: Dr. ir. I. (Igor) Nikolic TU Delft, first supervisor
Dr. J. (John) Posada TU Delft, second supervisor
V. (Victoria) Santos Federal University of Rio de Janeiro, Brazil, daily supervisor

An electronic version of this thesis is available at <http://repository.tudelft.nl/>.

"Industrial ecology at its basis is a social construction."

- Cohen-Rosenthal (2000).

Abstract

This thesis researches the interaction between the revitalisation of an industry through industrial symbiosis and its local workforce, via a case study on the sugar industry in Norte Fluminense, Brazil. Agent-based modelling is used to gain insights in the case study with regards to the workers' perception of their own status, power, their skills, (un)employment and the company's ability to hire those workers. The case is contextualised by the proposal of Santos and Magrini (2018) to sustainably develop the Norte Fluminense region through the implementation of an agro-industrial symbiosis network. It is analysed that an industry revitalised through industrial symbiosis could positively influence its local workforce in terms of job quality and occupational skills. However, this depends on the kind of industry involved, the incentives for the industrial symbiosis network for including the local workforce, and the context and history of that industry. The prerequisite for these positive effects is the provision of additional education needed for the workforce to be included in the revitalisation of the industry. When the appropriate education is organised, the workforce could positively influence the revitalisation of an industry by providing the local support that is needed for industrial symbiosis exchanges to take place. These exchanges are built on the mutual trust of the key personnel of the industrial symbiosis network. The emergence of an industrial symbiosis network from an existing industry should happen gradually; the education for the potential workforce and the creation of jobs should be aligned to avoid unnecessary mismatching between skills required and skills available.

Acknowledgements

In the half year journey of Industrial Ecology master thesis writing, my supervisors, other professors, colleagues, family and friends have been of great support. Especially I would like to thank my three supervisors Igor Nikolic, John Posada and Victoria Santos for their enthusiasm and dedication for this project. It motivated me greatly to work hard and try to achieve what Igor had explained with such detail in the beginning of this thesis: from the world that we know now, through in-depth research, to a world that is enriched with the insights of that research. Igor, even though you are a busy man, in our meetings you were always insightful, on the same level as me, and so full of ideas, that I could go on again for quite some time. John, even though your field of research was a bit less related to my thesis than we thought beforehand, you have helped me look at my research from a different perspective which aided the work interdisciplinary. Victoria, you were always there for me whenever I needed anything. Even when you moved back to Brazil, I could always ask you anything or discuss my ideas with you. Thank you for all this, it really made my thesis time surprisingly enjoyable.

Furthermore, I want to thank Jorge Moncada Escudero for his voluntary support in agent-based modelling and even help with some of my text. Gert-Jan Hofstede, for pointing me in the right direction in my search for social theories.

Finally, a shout-out to my fellow students, family and friends who helped with text, visuals, and discussed with me about my thesis and who would really dare being critical towards my work. Thank you.

*Frederique de Groen
Delft, March 2018*

Contents

List of Figures	xi
List of Tables	xiii
1 Introduction	1
1.1 Industrial symbiosis: one of the main branches of industrial ecology	1
1.2 Case study	3
1.3 Scope	3
1.4 Research design	4
1.4.1 Research questions	4
1.4.2 Approach	5
1.4.3 Model collaboration: who does what?	5
1.5 Reading guide	6
2 Revitalising an industry through industrial symbiosis: a social perspective	7
2.1 Complex adaptive systems	7
2.2 Agro-industrial symbiosis networks	8
2.2.1 Biorefineries	8
2.3 The social dimension of industrial symbiosis	9
2.4 Comparable case studies	10
2.5 Case study: the sugar industry workforce in Norte Fluminense	11
2.5.1 Brazilian sugarcane market	11
2.5.2 Norte Fluminense region	11
2.5.3 Revitalising an industry through industrial symbiosis	12
2.5.4 Proposal for revitalising the sugar industry in Norte Fluminense.	13
2.6 Indicators	14
2.7 Social perspective	14
2.7.1 Power and status theory	16
2.7.2 The power-status theory of emotions	17
2.7.3 Fields of opportunities and frames of reference.	18
2.7.4 Human behaviour modelling theory	19
2.8 Sub-conclusion	20
3 Using a social perspective in agent-based modelling	23
3.1 Why modelling?.	23
3.2 Agent-based modelling.	23
3.2.1 10-step process.	24
3.2.2 Why agent-based modelling?	25
3.3 Method	25
4 Conceptualising the world of the sugar industry workforce	29
4.1 Problems and relevant actors	29
4.2 The system - decomposed.	30
4.2.1 Workers	31
4.2.2 Companies	32
4.2.3 Union	33
4.2.4 The concept of a job and training	33
4.2.5 Interactions - rituals	34
4.2.6 Policy instruments and criteria	34
4.2.7 Environment	34
4.3 Sub-conclusion	35

5	Model implementation	37
5.1	Formalising socially aware agents	37
5.2	Model narratives	39
5.3	Model implementation	41
5.4	Verification	41
5.5	Sub-conclusion	44
6	Exploration and experimentation	45
6.1	Aim of the exploration and experimentation	47
6.2	Explorations.	48
6.3	Experimentation design	49
6.4	Experimentation outcomes - data analysis	49
7	Results	51
7.1	Emergent patterns	51
7.2	Model use.	57
7.3	Sub-conclusion	59
8	Discussion and recommendations	65
8.1	Discussion	65
8.2	Recommendations	68
9	Conclusion and reflection	71
9.1	Conclusion	71
9.2	Reflection	73
	Bibliography	75
A	Indicator selection	81
B	Assumptions	83
C	Software data structures	87
D	States and actions of agents and objects	89
E	Flowcharts	91
F	Historical data	103
G	Experiments	105
H	Current and proposed scenarios	109
I	Scarcity and abundance of workers	113
J	Subsidies	115
K	Characteristics thresholds	123
L	Characteristics increments	125
M	Power and status increments	129
N	Consultation FERAESP	135

List of Figures

1.1	Industrial ecology branches (Chertow, 2000)	1
1.2	The research aim is to gain insights in how an industry's workforce (4) is affected by, and affects, the revitalisation (3) of that industry (2) through industrial symbiosis (1), via a case study on the sugar industry workforce in Norte Fluminense, Brazil (5).	4
1.3	Research framework	6
2.1	Norte Fluminense region (red) in Rio de Janeiro State, Brazil (Abreu, nd)	12
2.2	Attributes forming the decision making process, adopted from (Pahl-Wostl and Ebenhöh, 2004)	19
2.3	The role of trust (2) is essential to a successful relationship between managers of businesses that want to initiate IS exchanges (1) and the approached business for exchange (3). The community, or local workforce (4), can enhance these social relationships. As result of IS exchanges it is expected that the ISN improves the social equity (5) within communities.	20
3.1	Agent-based model structure (van Dam et al., 2013)	24
3.2	Conceptual framework	26
4.1	Job quality (OECD, 2014)	33
4.2	System diagram	36
5.1	States and actions of the worker, company and union agents	38
5.2	States of the objects	38
5.3	General actions of the agents	40
5.4	Timeline sanity - percentage vacancies	42
5.5	Variability testing - average power of the workers	43
6.1	The number and type of companies over time in the more dynamic company scenario, 900 runs.	46
6.2	An example of a run with random company dynamics.	46
7.1	The six outcomes of interest over time with five different scenarios.	52
7.2	Average trust of the workers with different percentage initial workers measured to the number of jobs in 1999. There is a strong downhill negative linear relationship, Pearson's correlation coefficient $r = -0.79$	54
7.3	The percentage vacancies over time, compared to the proposed static company and dynamic company scenario, with different combinations of the value of the hiring and requalification subsidies, that are supplied annually. The number of workers is double the initial number of jobs.	55
7.4	Average skill level of the workers employed per company, over time.	57
7.5	The percentage job strain of the employed workers with different characteristic threshold levels in the proposed dynamic company scenario. In the top x-axis, three options for the low level of both the characteristics are used as input. In the right y-axis, three options for the high level of both the characteristics are used as input. The boxplots in the graphs represent the percentage of job strain over all employed jobs measured over the left y-axis, over the years shown in the bottom x-axis.	58

7.6	Optimistic IS development - interaction with the local workforce: insights from the case study. 1 = sugar industry; 2 = sugar industry's workforce; 3 = industrial symbiosis; 4 = initiator of the IS exchanges for an agro-ISN; 5 = trust of others; 6 = investigation of new industrial symbiosis exchanges; 7 = the potential future agro-ISN workforce; 8 = the proposed agro-ISN; 9 = education.	62
7.7	Insights of the case study applied to the circular economy concept. 1 = the appropriate education for enabling the industry's current workforce to change with that industry; 2 = industrial symbiosis; 3 = trust of others.	63
9.1	A optimistic view on the final conclusion. 1 = industrial symbiosis; 2 = an industry; 3 = revitalisation; 4 = an industry's workforce; 5 = the appropriate education; 6 = satisfaction; 7 = commitment; 8 = trust; = trust of industrial symbiosis network company managers. . .	72

List of Tables

2.1	Preliminary application of GRASP, adopted from Hofstede (2015)	16
4.1	Initial power perceptions of the agents	31
4.2	Initial status perceptions of the agents	32
G.1	Parameter values of the standard current and proposed scenario	106
G.2	Exploratory threshold and increment experiments for the proposed dynamic company scenario	108

Abbreviations

ABM	Agent-based modelling
CAS	Complex adaptive system
CE	Circular economy
EIP	Eco-industrial park
IE	Industrial Ecology
IS	Industrial symbiosis
ISN	Industrial symbiosis network

Introduction

This thesis aims to contribute to the field of industrial ecology, specifically to the branch of industrial symbiosis and the social dimension of modelling in industrial ecology. In collaboration with the PhD research of Santos and Magrini (2018), the potential of an agro-industrial symbiosis network in Norte Fluminense, Brazil, is investigated. Ms Santos proposes to revitalise the sugar industry in that region through a biorefinery-centred industrial symbiosis network. The thesis considers this proposed scenario as a case study to gain insights into how the workforce of an industry is affected by, and affects, the revitalisation of that industry through industrial symbiosis. Because of the complex adaptive nature of such a system, agent-based modelling is used. The context of the case and identified knowledge gap call upon a social perspective in modelling.

1.1. Industrial symbiosis: one of the main branches of industrial ecology

Industrial ecology (IE) stresses the importance of taking a systems perspective in analyses of amongst others material and energy flows, which results in multi- and interdisciplinary research (Lifset and Graedel, 2002). This thesis is contextualised by industrial symbiosis (IS), a main branch of the field of industrial ecology, see figure 1.1.

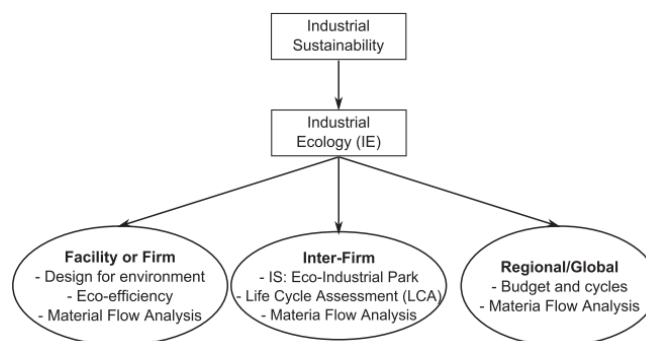


Figure 1.1: Industrial ecology branches (Chertow, 2000)

For this research, IS is defined as appears most commonly in literature: it "engages traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water and by-products" (Chertow, 2000). Industrial symbiosis is at the heart of eco-industrial parks (EIPs) (Agarwal and Strachan, 2006; Chertow, 1998), and application of IS benefits the three aspects of sustainable development: social, economic and environmental. The exchanges of materials, energy, water and by-products between companies, are further on called IS exchanges.

The social dimension of industrial symbiosis The social aspect of IS that is elaborately researched contains topics like the social relationships and shared norms between key personnel in industrial sym-

biosis networks (ISNs). Important social characteristics for IS include openness, trust, and communication. Research often investigates how and to what extent these characteristics influence an ISN (Ashton and Bain, 2012). However, *influence of and on the people who are involved in an IS but are not key actors directly influencing an IS, is lacking research*. These non-key actors influencing an IS are defined as the "external social dimension", and shall return under that name at a later stage.

Valenzuela-Venegas et al. (2016) state EIPs focus to "care about the life of people in local communities", and although its social impacts are not obvious and hard to quantify, jobs, life style and health in the local environment are said to be benefited. However, of the 249 indicators found by Valenzuela-Venegas et al. (2016) measuring EIPs concerning the three dimensions of sustainability, only 4% is social (e.g. job creation), and 4% combined social with environmental or economic (e.g. health). Moreover, in a recent comparison of IS indicators through agent-based modelling, Couto Mantese and Capaldo Amaral (2017) describe the indicators that are most widespread in literature. These are elaborated by Tiejun (2010) without mentioning the external social dimension. In addition, the absence of insights of IS on the people indirectly involved is also noted in related fields like the supply chain industry (Bansal and Mcknight, 2009).

Revitalising an industry through industrial symbiosis The 'organizing [of] self-organization', the designed emergence of industrial symbiosis networks and the success or failure of such networks are much researched topics to analyze the potential of developing EIPs (Chertow, 2007; Chertow and Ehrenfeld, 2012; Yap and Devlin, 2017, e.g.). But, very little research considers the revitalisation of an existing industry through the process of industrial symbiosis, as was revealed through literature review. A relevant example is the project GERIPA (Geracao de Energia Renovavel Integrada a Producao de Alimentos) by Ometto et al. (2007), a social and ecological agro-industry model based on agro-industrial symbiosis. This project aims to design an eco-industrial park which includes sugarcane and sorghum cultivation, cattle, forest reserve, industrial sectors, housing, hospital and leisure area, and - if approved - will be built on unused and marginal land and thus not within existing industry. The few cases that study the revitalisation of an industry through IS reveal that the local community can benefit in terms of well-being and job creation (van Berkel et al., 2009b; Taddeo et al., 2012).

Regarding the difference between transitions of existing industries or the implementation of industries built from the ground up, Boons et al. (2011) state that *"to ensure system change rather than system optimization, it needs to emerge from the existing system"*.

With the revitalisation of an industry, the necessary employees for new companies must be adequately skilled to be able to provide a workforce for this industry. One of the major challenges in terms of employment in most countries is the mismatch between skills available and skills required because of these swift and considerable changes in labour markets (OECD, 2017a).

The circular economy concept The closed loop system in an industrial symbiosis network, or eco-industrial park, is also the common base of, and pre-dates, the circular economy (CE) concept (Murray et al., 2017). The ideal of the latter is to turn the *linear economy* that takes natural resources from the environment and turns it into waste via production, into a "cyclical closed-loop system". Like IE (figure 1.1), the CE has been framed in three dimensions: firm, inter-firm wherein IS is included, and regional. In addition, industrial ecology is one of the schools of thought that served as a base for the development and refinement of the circular economy concept.

Although extensive research has been done on the origin and concept of the CE, few studies investigate the implementation and assessment of agricultural industries (Winans et al., 2017), like the sugarcane industry in Brazil. Further studies linking IS and CE point out that IS can help defining CE goals and methods on the local and regional level (Gibbs et al., 2005; Stahel, 2013).

The circular economy is also coupled to benefitting the three pillars of sustainable development. Again, the social component is lacking assessment (Murray et al., 2017; Winans et al., 2017), even though the most commonly used definition for sustainable development is to "meet the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987, p. 43). Therefore, the circular economy is redefined by Murray et al. (2017) as "an economic model wherein planning, resourcing, procurement, production and reprocessing are designed and managed, as both process and output, to maximize ecosystem functioning and human well-being". Because this definition takes into account the social pillar of sustainable development, this is the CE definition that will be used further on in the thesis.

Social modelling in industrial ecology

"Industrial ecology is taken to be the activity of designing and managing human production-consumption systems, so that they interact with natural systems, to form an integrated (eco)system which has ecological integrity and provides humans with a sustainable livelihood."

- Kay (2002)

Like Kay, Fischhoff and Small (2000) emphasize the importance of human modelling in industrial ecology. Until 1999, only the field of economics has been used significantly in achieving an understanding of, and predicting and shaping human behaviour through formal systems modelling. However, this so-called *normative* modelling is based on the principle that individuals take rational choices whilst being aware of all possible consequences of their actions, in an efficient marketplace. Human behaviour is too complex and unpredictable to render this realistically, and individuals make decisions that affect their environment significantly. On the other hand, *positive* models that aim to capture how people actually behave, show people's emotional, social, cognitive, and cultural determinants (Fischhoff and Small, 2000). With modelling - and not for example traditionally social quantitative or qualitative research methods - insights can be applied more generally even though there is only one case studied, because you construct the mechanisms that cause a certain behaviour. Agent-based modelling (ABM) is an emerging technique which allows adaptive 'agents' to interact with each other based on various rules of behaviour. This *positive* modelling approach can simulate the emergent behaviour of social systems (Epstein and Axtell, 1996), which is a great opportunity for industrial ecologists.

Knowledge gap From the research that resulted in the above-mentioned topics, the following knowledge gap is found that will be addressed in this thesis.

Knowledge gap

An understanding of the social effects of the revitalisation of an industry through industrial symbiosis.

1.2. Case study

Santos and Magrini (2018) propose a scenario for sustainably developing the Norte Fluminense region in Brazil through the revitalisation of the sugar industry. The proposed theoretical design enables the implementation of a biorefinery-centred agro-industrial symbiosis network (agro-ISN) in the studied region, which in the long term is expected to benefit the region in multiple social, environmental and economic aspects. This proposal is the main case study of the thesis.

To investigate the simulated effects of an agro-ISN on the external social dimension, an agent-based model is created in the context of the case study. The model will serve as a proof-of-concept, because other examples of similar models have not been found and there is no possibility of gathering data for calibration of the model. Furthermore, Ms Santos created an ABM of the sugarcane farms, sugar mills, biorefineries and other industries that will be attracted by the agro-ISN. As an addition, to illustrate the use of the model created for this thesis, the model can be combined with Santos' model; like industrial symbiosis, Santos' outputs will serve as inputs for my model and vice versa.

1.3. Scope

There is an abundance of factors that could be researched with the proposed agro-ISN in Norte Fluminense as a case study for ISNs affecting the local population and vice versa. However, the model will focus on the sugar industry employees and the subsidies necessary for them to reach a higher level of job quality and skills, a higher perception of their own status and power, a minimal unemployment level, and for the ISN the ability to fill their vacancies with locals. This choice was made because of the context of the case study, which will be elaborated on in chapter 2 and 4, and because more attention should be paid to power relations, labour conditions and governance systems in IE (Sahakian, 2016).

Santos' model covers the business and technical side of the agro-ISN; it contains the companies that produce and exchange all kinds of waste streams, their mass balances, and investigates options for different kinds of biorefineries and configurations of IS. The model created for this thesis will zoom in

on the individual, social aspects; it involves the workforce that is necessary to make such an industrial park a success.

With a time and space limitation, choices must be made to narrow down the scope of this research. With a case study in Norte Fluminense, Brazil, and the option of going to Brazil being too time consuming and inefficient because the language is not spoken by the author, all information necessary should be gathered from literature, some of it validated by Santos. This also limits the options of different types of people of the sugar industry workforce to be investigated, instead of for example including also their families, other locals that are employed in other industries, or consumers of the products from the sugar industry.

1.4. Research design

The thesis is defined by the aim, research questions and model questions elaborated on in this section. The research aim is visualised in figure 1.2; the same kind of visualisations will be used throughout this report to clearly convey the gained insights. The icons are always explained in the caption of the figure and will be used consequently in all visualisations.

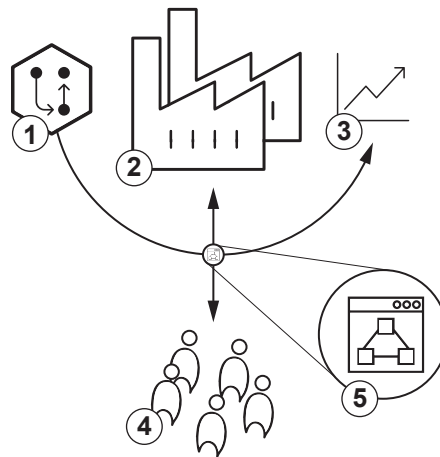


Figure 1.2: The research aim is to gain insights in how an industry's workforce (4) is affected by, and affects, the revitalisation (3) of that industry (2) through industrial symbiosis (1), via a case study on the sugar industry workforce in Norte Fluminense, Brazil (5).

The questions are divided into two categories: research questions and model questions. The research questions enable insights for industrial ecology, industrial symbiosis and the circular economy concept. Model questions are constructed for the case study at hand, and together with the research sub questions, will help answering the main research question.

As the model will be focused on job quality, (un)employment, skill level and the workers' perception of their status and power, the insights for IE, IS and CE will concern those factors, as well as the subsidies necessary to achieve certain levels in those factors. Furthermore, with the revitalisation of an existing industry as a scenario background, an objective is to compare a scenario with the ISN implemented and without.

1.4.1. Research questions

From a theoretical, more abstract perspective, this thesis answers the research questions posed below.

Main research question

How is the workforce of an industry affected by, and affects, the revitalisation of that industry through industrial symbiosis?

The main research question - which is answered in chapter 9 - is split up in sub questions to delve deeper into the main themes at hand. Combined, the sub questions can help answering the main

question. An indication is made in which chapter the question is answered; conclusions are elaborated on at the end of those chapters.

Research sub-questions

1. What is known about how industrial symbiosis influences the (potential) local workforce, and vice versa? *Chapter 2*
2. What is a possible method to simulate the effects of an industrial symbiosis network on the local workforce, and vice versa? *Chapter 3, 4 and 5*
3. What insights does the case study provide with regards to the interaction between an industry-revitalising industrial symbiosis network, the circular economy and its local workforce? *Chapter 2 and 7*

The model questions are specifically designed for the case study, and again answered in the chapter indicated and concluded at the end of those chapters. The main model question is answered in chapter 7.

Main model question

How is the current Norte Fluminense sugar industry workforce affected by, and affects, the proposed agro-industrial symbiosis network in terms of (lack of) employment, job quality, skill level, status and power?

Model sub-questions

1. What social theories can be used in an agent-based model to make agents socially aware, whilst being relevant for the main research question? *Chapter 2*
2. How are the social behaviour models or social theories applied in the case study? *Chapter 3 and 4*
3. How do the subsidy choices and modelled decision behaviour influence the effects of an agro-industrial symbiosis network on the current sugar industry workforce, and vice versa? *Chapter 7*

1.4.2. Approach

The method on how to approach the research questions stated above is developed from a complex adaptive systems perspective. As base of the method, there are five steps: literature review, conceptualisation, formalisation, analysis, and results and evaluation, see figure 1.3.

Firstly, the literature review gives an overview of preliminary research on theories and case studies of agro-ISNs, human behaviour, social behaviour, and covers the history, context and current situation of the case study of the sugar industry workforce in Norte Fluminense. Secondly, the conceptualisation phase is initiated with the conceptual research design, from which the problem owner is found and the actors are identified, the agent's behaviour is studied, important indicators are selected and the relevant theories on social and human behaviour are applied. Thirdly, the conceptualisation is formalised and divided into actions and interactions between the important actors, after which the model is implemented. Fourthly, the analysis phase consists of verification, experimentation, data analysis, validation and model use. Finally, the results of the model will be evaluated and applied to the existing knowledge of industrial symbiosis and the circular economy.

1.4.3. Model collaboration: who does what?

The aim of collaborating with Ms Santos is that both models can function separately but are more realistic when combined. Everything in this report is own work, except Santos' work in the combined model, which shall be mentioned explicitly. Santos' model simulates the business and technical side of the case study - from now on called the *technical model* - whereas the model presented in this thesis simulates the individual, social side, from now on called the *social model*. The technical model consists of the sugarcane farms, mills, industries and biorefineries that produce and exchange streams

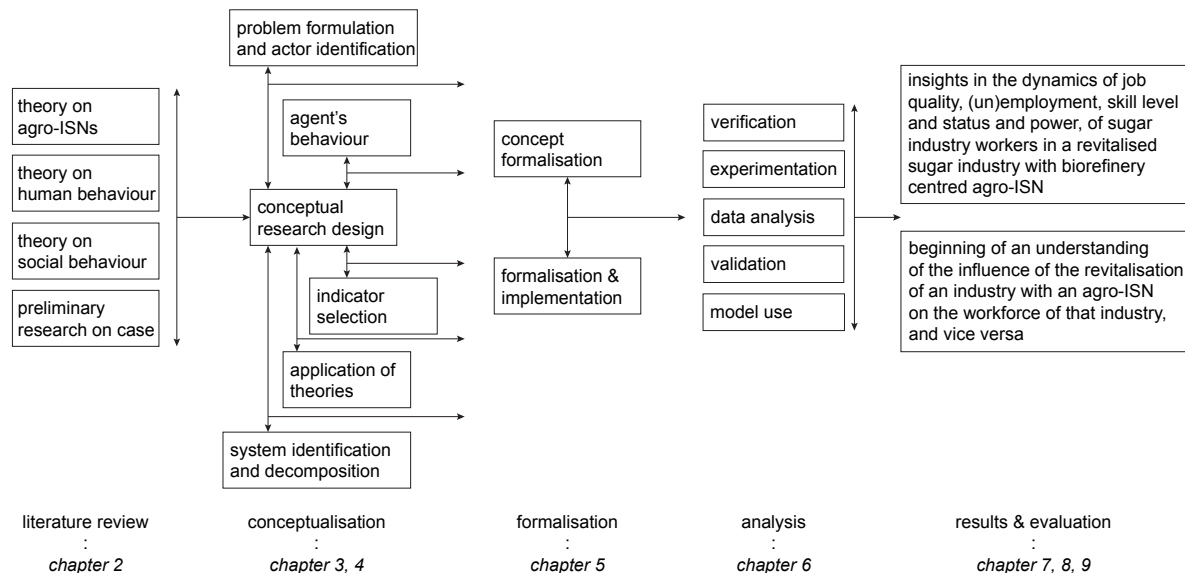


Figure 1.3: Research framework

of wastes, with the aim to find out which technological type of biorefinery and configuration of IS is "best" for the revitalisation of the sugar industry in Norte Fluminense. The "best" type of biorefinery and configuration of IS for Santos' research is determined by the resulting number of jobs created, the recycling ratio achieved, the amount of sugarcane produced and the lifetime of mills and biorefineries (Santos and Magrini, 2018). In contrast, the social model zooms in on the workforce of the sugar industry, including the companies and the union in the region to capture their world more completely.

When the models are combined, the behaviour of all agents will influence each other; the technical model influences the social model and vice versa. For example, the mill owners could go bankrupt because the market does not create enough demand. This means that all individuals working at that mill are fired. Another example, this time where the social model influences the technical model, is that of farm employees becoming more educated and resigning from their job to find a higher quality job that requires more skills.

1.5. Reading guide

This thesis is written consistently with the approach shown in figure 1.3. In chapter 2, the theoretical background information, the necessary literature reviews, preliminary case study context and history, and the theories used for conceptualisation are discussed. At the end of the chapter, the first research question and first model question are concluded. The method and tools used for this thesis research are elaborated on in chapter 3. Thereafter, in chapter 4, is explained how the world of the sugar industry workers is conceptualised. This chapter is concluded with answers to the second research question and second model question. Chapter 5 dives into the implementation of the model; this includes the concept and model formalisation. On the experiments that are performed with the model is elaborated in chapter 6. The results of these experiments are discussed in chapter 7. This chapter includes an example of the model use of the case study and again ends with a conclusion, this time the third and final model question and main research question. In the second last chapter - chapter 8 - is discussed how the model and results are and could be interpreted and possibly extrapolated, and recommendations for future research are elaborated on. The thesis is finalised in chapter 9, which covers the thesis' main conclusion and a personal reflection.

2

Revitalising an industry through industrial symbiosis: a social perspective

The theoretical perspective used in this research is a complex adaptive systems view (section 2.1) used on the system of the proposed agro-industrial symbiosis network. Agro-ISNs are reviewed in section 2.2 and section 2.2.1 zooms in on a part of the proposed agro-ISN: the concept of biorefineries. The workforce of ISNs is investigated in section 2.3. The literature on the social impacts of the agricultural and biobased sector, IS and agro-ISN is reviewed in section 2.4. Section 2.5 elaborates on the Norte Fluminense case. The second last section of this chapter reviews literature that is found to create socially aware agents. Finally, section 2.8 concludes the chapter by answering the first research and first model sub-questions.

2.1. Complex adaptive systems

Kay (2002) describes socio-technical systems as a class of complex adaptive systems (CAS). A socio-technical system can simply be seen as the social network of actors and the physical, technical entities that together form a CAS, like an agro-ISN.

Thinking in systems is inherently connected to industrial ecology, therefore, this research perspective is used throughout the thesis and underlies the model's design. Below, complex adaptive systems are firstly explained per concept, then as a whole.

Systems A system is "[...] a representation of an entity as a complex whole open to feedback from its environment (Ryan, 2008). More extensively explained by Ryan (2008), systems (1) are an idealisation; (2) have multiple components; (3) components are interdependent; (4) are organised; (5) have emergent properties; (6) have a boundary; (7) are enduring; (8) effect and are affected by their environment; (9) exhibit feedback; and (10) have non-trivial behaviour.

Adaptive In biology, the ability of an organism to *adapt* implies the results from natural selection: an alteration in the organism's structure or function by which it has a better fit for survival and procreation in its environment (The American Heritage Science Dictionary, nd). In the context of CAS, to be adaptive is to have "*improvement over time in relation to [the] environment*", by "*specific kinds of changes in response to specific types of stimuli*" (van Dam et al., 2013). The types of stimuli one adapts to must be constant or periodic (within a lifetime).

Complexity Complex is the conceptual opposite of simple. When a system is not-simple, it can be complex, and/or a special type of complexity: complicated. Real world systems are inherently complex; adaptive systems are even more so, because of its relationships between elements. Changes to complex systems are inevitable, and every small change alters the rules of that system in some way. When additions to systems are complicated, they will adapt themselves and force a change in the system until they are embedded. Viewed in the right way, these complicated additions can look

simple. It is very important to keep in mind the observer dependence, which includes what the observer finds important in a complicated system. One of the dimensions that are crucial in complexity dynamics, is time. Over time, complicated additions to systems can disappear into the total system complexity.

When the three previous concepts are put together, you have *complex adaptive systems*. One of its basic mechanisms is *chaos*; the most relevant features of these for socio-technical systems are explained. (van Dam et al., 2013) define chaos as "*complex behaviour, arising in deterministic, non-linear dynamic systems, when relatively simple processes or rules are repeatedly applied*".

Emergent behaviour is, however rarely predictable, always moving towards attractors or away from repellents. It is also the behaviour of the overall of CAS. Emergent behaviour is easier to understand than the mechanisms or processes that cause that specific behaviour. For example, human consciousness is thought of as emergent behaviour, which cannot be understood by examining separate parts of the brain. The reader is referred to (van Dam et al., 2013) for further elaboration on the topics of this section.

The above-explained concepts are the very basis of the agent-based modelling. This process is explained in chapter 3. The next section elaborates on agro-ISNs, the CAS under study.

2.2. Agro-industrial symbiosis networks

Agro-industrial symbiosis involves agriculture in the exchange of e.g. wastes, services and infrastructure in a cluster of industries. For example, waste heat of industries can be used to heat greenhouses, and in return, the agricultural waste can be converted into platform chemicals (Clark and Deswarte, 2015) that are used in those industries.

A search on Web of Science with the topic "agro-industrial symbiosis" generates only one result: Ometto et al. (2007) researched the strategies to implement an agro-industrial symbiosis network and its resulting benefits, in Brazil. As mentioned in chapter 1, Ometto et al. (2007) designed a system which included most things necessary for a self-sustaining new area: environmentally friendly agriculture and energy production and thus work, housing, leisure area, and so forth.

On the other hand, "agro-industry" is a more common name for this kind of industry and can include symbioses of all kinds. The sugar industry in Brazil is a much-researched topic in this field and typically involves the production of energy carriers (Macedo, 1992; Martinelli and Filoso, 2008; Pandey et al., 2000, e.g.).

A related topic comes up when the subject is taken even more broadly, i.e. including industrial ecology. Fernandez-Mena et al. (2016) state that a new field called "agro-industrial ecology" is necessary for mitigating environmental damage from agricultural food production. Specifically, they look at nutrient cycling in complex social-ecological systems; their identified approaches include Environmental Assessment tools for the ecological dynamics, Stock and Flow methods for organisation scenarios, and ABM for the social dynamics.

Fernandez-Mena et al. (2016) are the first proposing the field of agro-industrial ecology and find it a promising method to address issues in agro-food socio-ecological systems. This quite recent study points out that ABM can be the right tool to use when assessing the social side of an agricultural system, which is the case for this thesis.

To further explain the conceptualisation of the proposed agro-ISN, the following section will elaborate on biorefineries.

2.2.1. Biorefineries

The most comprehensive definition of the concept of a biorefinery is "[...] *the sustainable processing of biomass into a spectrum of marketable products and energy*" (IEA, 2008). The core activity of the concept includes a wide range of technologies that turn biomass resources into chemical building blocks, which are used for biofuels, chemical applications and other value-added products (Cherubini, 2010). A biorefinery can be a single facility or a network of facilities, and the necessary feedstock can come from agriculture, forestry, industries, households, and aquaculture. However, most of the existing biorefineries operate stand-alone and with feed and food competitive raw materials.

Biomass feedstock Sugar crops, like sugarcane, are one of the most used biomass feedstock, because of its carbohydrates. The sugar molecules must be extracted to make use of the carbohydrates,

after which they can be easily fermented to ethanol or processed into another chemical substance.

Lignin is the main component of another commonly used feedstock: lignocellulosic biomass. From the total dry matter of sugarcane, residues like sugarcane bagasse make up 15 to 25%. These non-carbohydrates cannot be fermented but can be used for chemical extraction or energy generation (Cherubini, 2010).

Technology In a biorefinery, several technological processes must be applied to obtain the required substance from biomass. The four main processes are (1) thermochemical (gasification and pyrolysis); (2) biochemical (fermentation and anaerobic digestion); (3) mechanical/physical (cutting and separation); and (4) chemical processes (hydrolysis and transesterification). Most common is to first mechanically reduce the size of the feedstock and to separate the feedstock components. Lignocellulosic pre-treatment, e.g. that of sugarcane bagasse, is also performed mechanically. Thereafter, a wide range of (bio)chemical reactions and processes can ferment or depolymerise the sugar molecules and proteins to derive chemicals, such as succinic acid (Cherubini, 2010).

Depending on the biorefinery's technology, it can fall into the category of high-tech industries. This is the case for the proposed biorefineries in Norte Fluminense, which aim to produce succinic acid. High-tech industries can involve a strong competition that can result in pressure on the quality of the relationship between bosses and employees (Harpaz and Meshoulam, 2004). Large investments must be made on the one hand to manage the job quality, while on the other hand, a complex system can be handled to track below-average performing workers (Harpaz and Meshoulam, 2004).

Products Broadly seen, there are two categories of products from biorefineries: energy and material products. The most important energy products include gaseous, solid and liquid biofuels. The most important material products are chemicals, organic acids, polymers and resins, biomaterials, food and animal feed, and fertilizers (Cherubini, 2010). In the case study performed for this thesis, the organic (bio-based) succinic acid will be the main product of the proposed biorefineries. This platform chemical can be converted into at least 30 different products (Santos, 2013; Santos et al., 2014) and it consumes CO₂ in its production process. The products that can be produced include butanediol, polybutylene succinate and polyurethanes (Santos and Magrini, 2018).

2.3. The social dimension of industrial symbiosis

As noted in chapter 1, important social characteristics for IS include, amongst others, trust. Although these characteristics apply to the key personnel in an ISN, support from the local community - in this case the workers - is essential in the creation of IS exchanges (Simboli et al., 2015). This community agreement must be sustained to be able to "*build a culture for sustainable local development*" (Simboli et al., 2015). Therefore, it is assumed that trust between the workforce of an industry and their bosses plays a key role in the development of an ISN.

One of the many studies that highlight the importance of trust in the realisation of IS exchanges (Hewes and Lyons, 2008; Chertow et al., 2008, e.g.) is the work on the development of trust in ISNs of Doménech and Davies (2011). Their analysis of the social mechanisms that allow for the successful emergence of an ISN, identifies that the development of a mutual trust requires time and regular meetings in person. Moreover, it is associated with a heuristic decision-making approach and a certain degree of reciprocity (Doménech and Davies, 2011). Comparing ISNs to other industrial parks with by-product and knowledge exchanges, the ability of ISNs to be more successful than the other industrial parks largely depends on their capabilities to develop embedded relations where trust is key (Doménech and Davies, 2011).

Continuing on this topic, the research of Hewes and Lyons (2008) on champions and the role of trust in EIPs is consulted. They analyse two successfully implemented cases of IS, of which the initiator of the IS exchanges took different approaches. However, in both cases, there was greatly invested in developing social relationships, where the community and local support proved key in promoting those relationships. The predominant themes that appeared in the interviews conducted by Hewes and Lyons (2008) included 'bringing people together', 'developing local support', and again, 'building trust'. These themes are all issues of trust and time; like Doménech and Davies (2011) analysed, the development of trust takes a considerable amount of time.

2.4. Comparable case studies

This section elaborates on different case studies conducted for the agricultural and biobased products sector, industrial symbiosis, and finally a brief mention of a discussion on agro-industrial symbiosis networks. Cases are chosen that are most similar to the case study in this thesis. Moreover, differences between methods used in the case studies, cultural and spatial differences will be taken into account.

Social impacts of bioethanol production in Thailand A recent case study of Papong et al. (2017) on the environmental and social impacts of bioethanol production from cassava and sugarcane molasses in Thailand is somewhat comparable with this thesis project. Regarding the social impacts, indicators that are used are the direct and indirect employment, wages, and occupational injury effects in the agricultural and industrial stages of the bioethanol production. The method used to identify these effects is a combined process-based and top-down approach, respectively using site-specific data and input-output analysis. Indeed, the method used by Papong et al. (2017) is different from the method used for this thesis, which should be considered when comparing the case with the thesis outcomes. Direct effects are measured by collecting data, while indirect effects of employment and work injuries are computed using input-output analysis. The results are compared with conventional gasoline production in Thailand.

Results show that bioethanol production employs 15 - 18 times more people in total, income is about 14 - 21 times more, and there is a higher risk of fatal occupational injuries than with the conventional gasoline production supply chain. The biggest employment contribution (70%) in the molasses supply chain comes from the cultivation of sugarcane. However, the quality of this kind of job is considered low. Working conditions are similar to that of agricultural jobs in Norte Fluminense: workers are mostly daily and seasonally employed, are low-skilled and the health conditions are poor. On the other hand, high agricultural employment rates can indicate rural area development (Papong et al., 2017). The higher income achieved with bioethanol production could also imply an increase of income distribution in agricultural workers in the countryside. However, it should be noted that this distribution is measured in US\$/GJ of energy produced, so maybe less bioethanol is produced with more workers, compared to more gasoline, produced with less, higher educated workers. Finally, the occupational injuries in the cultivation stage are all non-fatal, mainly because of the low amount of mechanized operations at the cassava and sugarcane farms. For the process of sugarcane to bioethanol, half of the fatal accidents occur indirectly in feedstock processing and the remaining occurs indirectly in the conversion of molasses to bioethanol. Advised is to encourage health and safety training throughout the whole supply chain of bioethanol from cassava and sugarcane.

Social impacts of sugarcane ethanol in Brazil A less recent study by Goldemberg et al. (2008) investigates the environmental and socio-economic impacts of ethanol production from sugarcane in São Paulo State, Brazil. Amongst the social impacts, jobs, working conditions, wages, income distribution and land ownership are researched. However, this is more a summary of statistics and only focused on São Paulo State, whereas for this thesis the interest lies in the interaction between the sugar industry and its workforce.

Industrial symbiosis The social dimension of IS is generally explained by Bansal and Mcknight (2009). The research distinguishes the three pillars of sustainable development as economic prosperity, environmental integrity and social equity. The latter is explained that all people including future generations are provided equal opportunities. The three pillars are interconnected and in the best situation, they can create a win-win-win situation, for all three aspects of sustainable development. It is said that this ideal can be constructed with IS.

On the social dimension, theoretically, IS enhances the social equity within communities because it provides the need for strong and professional relationships between the involved actors. These communities share a sense of collaboration and responsible orientation (Bansal and Mcknight, 2009). It must be noted that the strong and professional relationships apply to the business managers and owners that are actively involved in the development of an ISN; no research is conducted for the relationships of their employees.

Agro-industrial symbiosis networks As explained in section 2.2, agro-ISNs are not yet a common concept that is written about. In the existing body of literature, no social effects can be found around this specific concept or related terms such as agro-industry.

2.5. Case study: the sugar industry workforce in Norte Fluminense

The thesis researches one elaborate case study, therefore this chapter is fully dedicated to the context of that case study: the Brazilian sugarcane market, the Norte Fluminense region, and how this region could be developed through industrial symbiosis.

2.5.1. Brazilian sugarcane market

In the largest South American country, sugarcane production already existed from 1540, in the time of the colonization (IBGE, 2016). Nowadays, Brazil is the biggest sugarcane producer in the world with a yearly average of almost 500 million tonnes of sugarcane produced. In addition, sugarcane is the third most produced commodity in the world (FAO, 2014).

Sugarcane is currently a major source of income in the Brazilian agricultural sector (Ometto et al., 2007). In Brazil in 2014, of its 80,017,000 ha of arable land, 13% is harvested sugarcane (FAO, 2014). The two main products derived from sugarcane are sugar and alcohol. Ethanol, which can be made from alcohol, is an alternative fuel for road vehicles. Its use started shortly after the Oil Crisis in 1973 when oil prices quadrupled. Two years after the crisis, the ProÁlcool project or National Program of Alcohol was created by the Brazilian government to stimulate the use of alcohol from sugarcane, to reduce the country's dependence on oil import. The ProÁlcool project has since been continued and revived by, for example, promoting the production of cars that are especially designed to drive on a mix of ethanol and gasoline. In addition, the sugarcane bagasse that is left over after sugar and alcohol production contributed greatly to the amount of renewable energy in Brazil. In 2010, 19.3% of the energy mix consisted of sugarcane products (Hofsetz and Silva, 2012).

Even though Brazil is world's biggest producer of sugarcane, the absolute amount of sugarcane produced is stagnating or even in decline (FAO, 2014). Furthermore, social and environmental impacts that can be indicated are amongst others biodiversity loss, burning, pesticides, high water consumption and erosion. The current system in Brazil - the Conventional Sugar and Alcohol Production System (CSAPS) - is mainly based on single-crop techniques with the intensive use of fire, water, fertilizers and pesticides (Ometto et al., 2007). The most negatively influencing environmental impacts are caused by the exploitation of rural workers; burning organic residues on sugarcane harvest ground, intensive use of fertilizers and pesticides, the inadequate use of distillery effluents and the concentration of land and income through unfair land tenancy (Ometto, 2000).

2.5.2. Norte Fluminense region

History The Norte Fluminense region lies in the north of Rio de Janeiro State, Brazil (Figure 2.1). The geographically extensive and flat region has always been rich in agricultural activities like the production of sugarcane. Following an exploration and later consolidation of oil and gas fields in the Campos Basin in the late 1970s (Santos and Lima, 2015), the number of sugar mills declined from 18 to 3 sugar mills in the last 30 years (Macedo, 2007; Santos and Magrini, 2018). The area of sugarcane crop farmland has decreased by 81.5% from 1990 - 2015 (Santos and Magrini, 2018). Because of this shift in activities in the region in the period between 1970 and 2000, there was an intense migration from rural to urban areas (Santos and Lima, 2015).

Economy There are two major sugarcane-producing regions in Brazil, one in the south-central and one in the north-east. Norte Fluminense falls outside of these regions defined by UNICA (2016). Nowadays, the Norte Fluminense region's economy is mainly based on oil activities. Because of the off-shore oil extraction, many industries go to cities in the municipalities of Campos dos Goytacazes and Macaé since they are at sea. Respectively, the share of industry as a percentage of the total gross value added (GVA) for these municipalities was up to 85% and 49% in 2012 (Wójtowicz, 2016). In the same year, the agriculture sector added only up to 19% in some municipalities of Norte Fluminense, to the region's total GVA. However, the municipality of Campos dos Goytacazes in Norte Fluminense was and currently still is one the main producer of sugarcane in Rio de Janeiro State. Furthermore, the GDP per capita in Campos dos Goytacazes was in 2012 one of the largest of the country (R\$95,500), compared

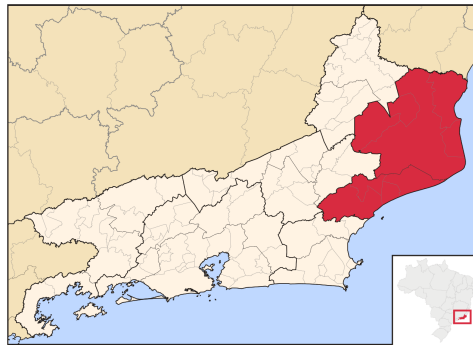


Figure 2.1: Norte Fluminense region (red) in Rio de Janeiro State, Brazil (Abreu, nd)

to the average of less than R\$22,000 in that year (Wójtowicz, 2016). Besides those two municipalities, Norte Fluminense does not show great development, being linked more to livestock farming and other agricultural activities.

Demographics Norte Fluminense region is located in the area between Rio de Janeiro and São Paulo that is, by some researchers, described as a so-called Megalopolis (Wójtowicz, 2016). Population densities in the Brazilian Megalopolis are highest in the metropolitan areas of Rio de Janeiro and São Paulo, and lowest in the Norte Fluminense region, with 92 people per km². However, in the time period of 2000 - 2014, the region experienced remarkably high population growth rates compared to the rest of the Megalopolis. Especially in the period of 2000 - 2010, this number could be as high as 11% annual population growth in the south of Norte Fluminense. Most of the inhabitants - around 70% - live in urbanized areas.

The high GDP mentioned in the previous paragraph does not comply with the Human Development Index (HDI) of Norte Fluminense. The HDI is the sum of a combination of indicators for education, life expectancy and per capita income, used to rank countries or areas in their human development progress. The ranking goes from 0 to 1, with 1 as the 'most developed'. Only in Macaé municipality the HDI is between 0.740 - 0.779, for the remaining of Norte Fluminense the HDI is between 0.611 - 0.719. This could suggest that there is no direct relation between a high GDP and the quality of life of inhabitants. In addition, it is possible that GDP and the power to create a better living environment is unequally divided among the residents.

Social issues The sugarcane production industry is employed by local and travelling workers. The latter are nomads from various parts of the country, seeking for better employment and income, following illusory promises from their contractors (Silva, 1999). The work on the plantations is physically hard. It is common to have no formal contract and no coverage of social security, a low wage, and the work causes serious health risks (Macedo, 2007). However, the workers are low skilled, illiterate and have few chances of inclusion in the dynamic and competitive labour market; the plantation work provides an important source of employment for this significant segment of the population.

Throughout the development of the sugarcane production industry, environmental claims led to new regulations requiring partial or full mechanisation of sugarcane harvesting, avoiding the local pollution from burning. Indeed, the burning of sugarcane crops for harvesting is mandated to be over by 2020 (COAGRO, nd), especially in the most productive regions. Already, measures are in place to facilitate this law.

At this moment, the region is highly dependent on non-renewable resources and a volatile market (TWB, 2005). It still struggles with inadequate health care for its inhabitants, urban infrastructure problems, housing deficit and slums. On top of that, 32% of the population is poor (Santos and Magrini, 2018).

2.5.3. Revitalising an industry through industrial symbiosis

As mentioned in chapter 1, only a few studies consider the revitalisation of an industry through IS. Of the six studies that were found, four research cases in Japan. Two analyse the Eco-Town program, which aimed to revitalise the local industry while solving the waste management issues (van Berkel et al.,

2009b; Ohnishi et al., 2012); one quantitatively analyses industrial and urban symbioses in Kawasaki (van Berkel et al., 2009a), of which both of the symbioses types have been implemented to revitalise the industries there; the last one researches the combination of IS with a combined heat and power plant (CHP) utilising the local sugarcane industry (Kikuchi et al., 2015). Only van Berkel et al. (2009b) mentions social benefits from the Eco-Town program; in terms of amenity and productivity, respectively the local community benefits from improvements in environmental and life quality (i.e. corporate social responsibility), and the society as a whole benefits from job creation and community investments.

The other two studies involve cases in the Abruzzo region in Italy: Simboli et al. (2015) regard the potential of industrial ecology tools, i.e. industrial symbiosis, for the local agri-food clusters; Taddeo et al. (2012) analyse the potential of IS to revitalise a historical chemical site. The latter is most similar to the case and proposal of Santos and Magrini (2018) for revitalising the sugar industry in Norte Fluminense; the chemical site in Abruzzo has faced a decline in industrial activity and because of the global economic crisis has to inventively reconfigure the industry (Taddeo et al., 2012). The local government funded the exploratory research of Taddeo et al. (2012), and due to the before-mentioned reasons, the choice was made to develop the industry through industrial symbiosis. As similarly analysed by Santos and Magrini (2018) for the Norte Fluminense case, the local community in Abruzzo benefits from the revitalisation through IS via job creation (Taddeo et al., 2012).

Thus, it can be concluded that the local community can benefit from an industry revitalised through industrial symbiosis in terms of well-being and job creation.

2.5.4. Proposal for revitalising the sugar industry in Norte Fluminense

The following paragraphs elaborate on the scenarios that Santos and Magrini (2018) propose for regional/local development in Norte Fluminense through industrial symbiosis. Four scenarios are developed: the reference or baseline scenario, and the short-, mid- and long-term scenarios. At the start, there is no agro-ISN, and the scenarios work towards a situation when there is a biorefinery that attracts more and more other industries, resulting in an agro-ISN.

Reference The reference scenario consists of sugarcane farms, sugar and ethanol production facilities and the combined heat and power plant. The farms supply sugarcane to the sugar production facilities, which produce bagasse, filter cake and molasses as by-products. The bagasse serves as feedstock for the CHP, while the ash from the CHP and the filter cake from sugar production are used on the farms as fertilizer. The molasses go into ethanol production, which results in CO₂, vinasse, used yeast and fusel oil waste streams. All of these are disposed of, except the vinasse, that is recycled by the farm as fertilizer.

The above-mentioned streams do not compose of the complete picture of this system, there is a remainder of liquid waste: boiler effluents, i.e. condenser effluents from sugar production and phlegm from ethanol production. As can be concluded from the recycled streams, there are already five internal symbiotic streams, however, they do not comprise of an ISN.

Short-term Short-term interventions in the reference scenario include the diversion of sugarcane bagasse from the CHP to the biorefinery. The latter consists of three separate units: pre-treatment and separation; saccharification and co-fermentation; and concentration and recovery. Estimated is a total production of 93 thousand tons of bio-succinic acid (bio-SA). This change in the system results in eighteen waste streams, of which eight from the existing sugarcane mill, six from the biorefinery, and four from both. As a replacement for the sugarcane bagasse, the CHP would now be fuelled with straw recovered from sugarcane cleaning and the dry lignin from the pre-treatment process. A fraction of the CO₂ from ethanol production would be used with the bio-SA fermentation. Furthermore, it is found that twelve waste streams can be completely or partially be used in the mid- and long-term scenarios.

Mid-term In this period, the system is transformed to the hypothetical regional agro-industrial symbiosis network that has been mentioned before. There would be exchanges of waste material between the biorefinery and the already existing 28 industrial sectors in the Norte Fluminense region. Four of the industrial sectors can take in five waste streams: the remaining CO₂ would go to a soft drinks producer; the fusel oil would be used by a distilled spirits manufacturer; the used yeast is recycled at an animal feed producer; and the bio-SA would be feedstock for an industrial surfactants manufacturer. Again, recycling options are discovered for the long-term scenario.

Long-term To consume the remaining waste streams, a new effluent treatment facility would be introduced. Again, a biogas production unit would be installed in this facility. The biogas would also serve as fuel for the CHP. The by-product lignin would be used by an adhesive manufacturer, and the filter cake from sugar production would be used as feedstock for wax manufacturing. To avoid the costs and environmental burden from recycling lube oil, a lube oil re-refinery would be deployed. The heat of atmospheric emissions like flue gas and particle matter would be recovered before its release, while the off-gases from bio-SA fermentation would be internally recycled.

The potential benefits of the proposed agro-ISM are estimated without the sugarcane bagasse that is fully used in the CHP in the reference scenario, without vinasse and other effluents from the sugarcane mill. Eventually, the solid and waste that is diverted from the landfill are respectively 213,943 t/y and 36,000 t/y. The amount of CO₂ emissions captured is estimated at 54,668 L/y and 52 jobs are created.

2.6. Indicators

Indicators provide specific information on the state or condition of something. In this case, social indicators are going to be used to measure the job quality of the sugar industry workers in the Norte Fluminense region. This section elaborates on the theory of selecting indicators. Widely used social indicators like the Human Development Index are not used for this case study, because of the lack of information accessible and the different focus of this ABM. The HDI, as explained in section 2.5.2, is not focused on employment; which is the case for this thesis. Therefore, a specific search for the right indicator is conducted.

Selection of indicators A selection of indicators will be conducted similarly to the comparison of frameworks for analysing social-ecological systems by Binder et al. (2013). They use main criteria for an initial selection of the frameworks they want to compare and contextual and structural criteria for the actual comparison of the frameworks. A literature research of peer-reviewed journals and books provides a list of frameworks that comply with the initial criteria. Contextual criteria are then used to describe the frameworks, however, this is out of the scope of this research. Structural criteria are used to compare the frameworks, and each criterion is coupled to a question that is found in relating literature. The structural criteria are divided into three categories: social system, ecological system, and social-ecological system. For all three, questions are asked how the system is conceptualized, and how the dynamics within and the interactions between the levels of the system are considered. For the social systems, these are for example learning processes, decision making and negotiation. Also, the framework can interact on four different social scales (Miller, 1978; Scholz, 2011):

- Macro, i.e. society
- Macro →micro, i.e. society influences the individual
- Micro →macro, i.e. how individual decisions influence society
- Micro, i.e. only individual decision making

Furthermore, a distinction is made between a bidirectional or unidirectional interaction between the social and ecological systems. The fourth criterion divides the frameworks into action- and analysis-oriented. Analysis-oriented frameworks would be providing general information that can be used for multiple purposes, like to formulate or approach different research questions. Action-oriented frameworks enable intervention in the socio-ecological system, for example, to decrease the vulnerability of local communities (Hinkel and Bisaro, 2015). Finally, guiding questions are set up to choose the framework that is most applicable to the research at hand.

Only a few of these steps are taken because of the limited amount of social indicators available in literature, these are described in chapter 3.

2.7. Social perspective

The following sections explain the theoretical foundation for conceptualising and formalising the case study of the sugar industry workers in Norte Fluminense into an agent-based model. Firstly, an overview is given of some widely applied social theories. Secondly, one of the theories of that overview, the power and status theory, is elaborated on in section 2.7.1. Thirdly, in section 2.7.2, the power-status theory of emotions is discussed. Fourthly, a theory based on the life of the sugar industry workers in

Pernambuco, Brazil, is explained in section 2.7.3. Finally, a modelling theory that aims to represent human behaviour in terms of personality traits is discussed in section 2.7.4.

Overview of social theories

Social structures can be seen on a macro and micro scale. The former studies the effect of whole populations and societies on individuals, and the latter studies every day, face to face interactions between individuals or small groups, and its effects on the larger patterns of society. These two sociological fields are of great importance for the research of how an industrial symbiosis network affects its employees, and how individuals affect the ISN. In this section, a few of these sociological theories will be discussed.

Theory of planned behaviour One of the most widely applied behavioural theories is the theory of planned behaviour (TPB) (Ajzen, 1991), which originates from the field of social psychology. In the TPB, it is assumed that people are rational, make systematic use of the knowledge available and consider the consequences of their behaviour before they decide to (not) act in a certain way (Ajzen, 1991).

Opportunity cost theory Opportunity cost is the anticipated cost of the best option after the option of choice (Buchanan, 1991). For this concept to be of value, scarcity and choice must be present; the opportunity cost expresses the basic relationship between these two. Scarcity introduces the necessity of choice; that of rejected and selected alternatives. The opportunity cost can only be defined if there are alternative options to the choice an individual wants to make (Buchanan, 1991).

Conflict theory On a greater scale is Karl Marx' conflict theory. He believed that inequality in a population would fuel a change in a society. The conflict theory describes that society consists of institutions that benefit the powerful and create inequalities. This causes large groups of people being at odds with each other until the conflict is resolved. The downside of this theory is that it only takes into account drastic change, but does not involve any stability or unity.

The three above-mentioned theories are widely used for all kinds of sociological research. However, the sugar industry workers are people and thus not rational, and using the TPB would bring down the level of realism in the ABM. Opportunity cost can be seen as more realistic and less rational since the comparison that a person wants to make exists of the options that are perceived by that person. However, costs are not the only aspect of these agents' world, and economics is not the right way of measuring aspects of the life of the sugar industry workers (de L'Estoile, 2014), as explained in section 2.7.3. Finally, the conflict theory does imply a change in the system in Norte Fluminense, however, the scale is not appropriate for this case because the individual lives of the sugar industry workers are not accounted for. More appropriate theories are found in the field of social simulation and explained in the following paragraphs.

Applied social theories

The theories that are applied to conceptualise the case study at hand are described in the following sections, although first is elaborated on the theories that could be used to create socially intelligent agents.

Socially intelligent agents Hofstede (2015) outlines the urge for and initiates the development of a method to model agents with social intelligence. This paper provides a solid basis for the theories that will be applied to the model. An outline of the overall theory is discussed below, the main theory that is used is explained in detail in section 2.7.1.

In a person's early life stages, social intelligence is developed through an acquisition of norms and values. Next to that, people have innate drives and motives that are profoundly social. GRASP captures the perception of the social world that people experience and consists of Group identity, Rituals, Affiliation, Status, and Power (Hofstede, 2015). The theory is developed from the perspective that artificial intelligence agents are like children; they still have to learn about the social world and do not yet think in categories from any civilization. The major difference between AI agents and children is that the former lives in a very limited and specific world, while children have to learn to understand the full

complexity of the real world. However, as children learn, GRASP can be used for agents as the "mental architecture of social life that underpins and precedes their reasoning in any particular situation" (Hofstede, 2015).

As mentioned before, there is a range of social theories from micro to macro scale. Hofstede (2015) divides the approaches that substantiate his GRASP theory in levels of (1) all people, of a (2) single group of people, and of the (3) individual. At the first level, the power and status theory by Kemper (2011) is used as a generalised theory across people to present the dynamics of social life. This level represents that people recognise rituals, categorise other people in groups, and are driven by affiliation, power, and status. For the second level, culture, social identity and rituals are valued as the characteristics of that specific group of people. On the level of the individual, there are variations in capabilities, motives, and attributes: people have different personalities, no matter in what group or culture their social world exists in. This level makes use of amongst others the power-status theory of emotions (Kemper, 2006).

The power and status theory and the power-status theory of emotions are the most compatible with the case study. Power struggles and status deficits have been the norm rather than the exception for sugar industry workers in Norte Fluminense. Furthermore, emotions function as a warning to people about dynamics in the power-status relationships, such as threats or opportunities. The agents that are experiencing these emotions should be aware of their actual and ideal state, and whether there is a chance to achieve this perfect state or not. The opportunities of the agents are also explained by another theory, not mentioned by Hofstede (2015): the theory of fields of opportunities and frames of references by de L'Estoile (2014) (section 2.7.3). Besides that, the level of the single group of people is taken into account by distinguishing different agents: the sugar industry workers (workers), companies, and the union. In this aspect, the agents can divide their world into 'us' and 'them', and be in the group with a most similar status as themselves. However, the agents cannot choose or change their social identity, since this is irrelevant to the model question. The agent's culture might be an important influence on the choices of the agents, however, this is not taken into account due to time limitations and the lack of a method on how cultural characteristics might influence the decision-making of the agents.

A preliminary application of GRASP to the case study is shown in Table 2.1, of which the different elements will be more elaborated on in chapter 4. The social elements in Table 2.1 are perceived by the sugar industry workers, and relative weighing is applied to power and status, ranging from insufficient (-), to adequate (o), to excessive (++)

Table 2.1: Preliminary application of GRASP, adopted from Hofstede (2015)

	<i>workers</i>	<i>companies</i>	<i>unions</i>
groups	us	them	us
rituals	report to union	hire people	organizes strikes
	participate in a strike	fire people	negotiates with companies
	take another job	increase resources / demands	requalifies workers
	participate in job training	decrease resources / demands	
affiliation	"friends" with company or		
	"friends" with union		
status	-	o	+
power	-	++	+

2.7.1. Power and status theory

The power and status theory by Kemper (2006) holds that there are two central dimensions operative when humans interact: power and status. Social relations, the actions directed to, with, for, and against each other, decide who gets what of the available benefits and rewards, and by what means. In a relationship, to have power is "to be able to coerce others to do what one wants them to do even when

they do not want to do it" (Kemper, 2006).

In a relatively stable power-relation where one actor has structurally more power than the other(s), we can predict that the one holding the power will obtain his or her way more often than the other(s) (Kemper, 2006). This involuntary compliance can be obtained through power tactics like physical and emotional violence. Once a stable power relation is established, these kind of power moves are quite rare. Status, on the other hand, is voluntary compliance: people happily support, approve, respect, accept and admire others without obligation. In a relationship, these benefits are rewarded to actors with a high status. Like power, a stable status relation follows a structure in which status is conferred and claimed in a set pattern, according to the theory of Kemper (2006).

The before-mentioned interactions occur at **micro-level**. At the **macro dimensions**, the power-status theory can be applied with a change of terminology. At the societal level, freedom and justice are more applicable instead of respectively power and status. Social movements, like the sugar industry unions, are often motivated by *freedom* - the moderation of power - or *justice* - an equal distribution of the benefits (Kemper, 2006).

When actors have, to their own perception, sufficient power and status, they need to do little to maintain that state. When there are other actors in the relationship that have too much power or actors think he or she has too little power or status, they are motivated to make a change in the relationship (Kemper, 2006). This can either be a reduction of the other's power or status, or an enhancement of the actor's own power or status. Actions not related to using power tactics or conferring status are the **meta processes** that an actor will engage in when they feel a real or imagined power or status deficit (Kemper, 2006). The relevant actions for the Norte Fluminense case study for a power and status deficit are explained below.

Power deficit Actors feel vulnerable when they lack the power to defend themselves and are therefore provoked to engage in the following activities (Kemper, 2006). *Dependency reduction* in a power-status structure of one person on another, leads to a reduction in the power of the other, however, this reduction of dependency has been achieved. When a dependency reduction cannot be achieved or is irrelevant, *coalition-building* can be a strategy to act against the one whose power is opposed. Actors in a coalition can have different motivations to participate in the coalition; from a grievance against a common enemy to receiving satisfactory benefits from the one who feels the power deficit (Kemper, 2006).

The last action mentioned in the status-power theory, *bluffing, propaganda, and disinformation*, is not taken into account because of the great level of detail it entails. Furthermore, it is irrelevant for the case study: no incidences of bluffing, propaganda or disinformation are found in the literature review on the case.

Status deficit According to the theory of Kemper (2006), a status deficit is an emotional state of feeling that one does not receive the appropriate amount of respect, approval, acceptance, appreciation, or love. As a consequence, an actor might try to obtain a higher status by engaging in the following activities. *Formal attainment according to universalistic criteria* is one of those activities: in general, higher education or preparation for a superior occupation are regarded as status-deserving (Kemper, 2006). This is not only the case within the context of that education or occupation but outside as well. Another category of activities is *normative appeals*: in the context of dealing with long-standing traditions or in institutions, the status-deficit actor may appeal to norms of justice or fairness (Kemper, 2006). This appeal can range from taking legal actions to a simple conversation where the injustice is claimed. When the others in the group do not feel that there is any injustice, this action can have an opposing effect. Then, the actor who appealed to the norms may be denied deserving status in such a situation, and be regarded as "troublemaker".

The eleven other forms of acting on a status deficit are not taken into account because they go into the small details of interactions between people in groups. For the case study, the most important actions are those directed from a member of one group to a member of another group, such as from workers to their bosses. Formal attainment and normative appeals can be regarded as such.

2.7.2. The power-status theory of emotions

Important aspects of the result of power-status relations are the accompanying emotions. The power-status theory of emotions (Kemper, 2006) is derived from the notion that a *"large class of emotions*

results from real, imagined or anticipated outcomes in social relationships" (Kemper, 1978). When two people interact in a power-status relationship, there are 12 possible outcomes in terms of their power-status structure, according to Kemper (1978). Actor A and actor B's power or status can either rise, decline, or remain unchanged. Because both actors might have a change in their status and power, here called A's and B's relational channels, there is a total of 81 possible sets of outcomes in the four relational channels. Every relational channel produces an emotion, and thus four different emotions can occur. However, there will be a dominant emotion that will reduce the interference of the less intense emotions in the other relational channels. In a stable social relation, like the sugar industry workforce has with their company, the power-status dimensions that are perceived can be felt as *insufficient*, *adequate*, or *excessive* (Kemper, 2006). In terms of interaction between two people, emotions occur from his or her own status and power, and the other's status and power (Kemper, 2006).

For the studied case, the emotions resulting from their power-status relations are not taken into account for the actions that the agents undertake. An option is to implement emotions as results of the agent's status and power. However, to say that certain emotions would then influence their actions, and especially how they would influence their actions, goes beyond the scope of this thesis. Furthermore, psychological studies on the sugar industry workforce would be needed, which are not available or obtainable in the present time.

2.7.3. Fields of opportunities and frames of reference

The social world of the sugar industry workers cannot appropriately be measured by economic theories (Coelho et al., 2006; Martinelli et al., 2010; de L'Estoile, 2014, e.g.). With calculability as one of the defining factors of our world nowadays, uncertainties must be contained in rationalisation and predictions of the future. Efforts to reduce uncertainties or estimate the probability of a future event is considered in these economic theories. Suggesting to move beyond an economic framework to investigate the "life situation of the poor [on former sugarcane plantations in Northeast Brazil]", de L'Estoile (2014) proposes to explore the *fields of opportunities* and *frames of references* that structure the life of the sugar industry workers.

In the early 1990s, people that worked on sugarcane farms in Pernambuco, the Northeast of Brazil, have been living in a continuous state of volatility, which became the 'normal' state of being. De L'Estoile (2014) calls this structural feature *radical uncertainty*, which consists of all the things that are completely out of one's control, for example, a failed harvest caused by climate change. If radical uncertainty is distinguished by unpredictability, *relative uncertainty* depends on how one sees its own social world (de L'Estoile, 2014). This kind of uncertainty is determined by one's norms and values; in Pernambuco, the interactions between workers, their families, and the companies they work at follow the norm of both negative and positive reciprocity. However, one does not know for a fact that the interacting other person follows this norm and will respond the way one expects; this is considered as relative uncertainty.

Both the types of uncertainty make up the frame of reference and the daily expectations of the sugar industry workers (de L'Estoile, 2014). Over time, people have developed ways to deal with these uncertainties. In the time that workers had no stability, legal protection or social security, they relied entirely on their loyalty towards and relationship with the company boss. This relationship was described as *reciprocity* and "*friendship*" (de L'Estoile, 2014); the "good boss" would, for example, bring a very sick family member by car to the hospital as an act of friendship. This description was also used for the worker's relationship with the unions that were formed later, which sometimes resulted in conflicting loyalties towards the worker's bosses and unions (de L'Estoile, 2014). The life of the sugar industry workers in Pernambuco changed entirely during big land reform projects in late 1997, and while some aspects may have increased in stability, other aspects of their lives increased in uncertainty. In this respect, most of the workers continued to act according to the frame of reference of the old sugar industry world by being loyal to the friends who are socially more powerful than one's self.

De L'Estoile (2014) concludes that one needs friends of the same social status, to help on a daily basis through reciprocity, and friends that are of higher social power or status, to help in case of a crisis, e.g. a very sick family member. Furthermore, these "friends" that one has - double quotation marks are used because the workers were not treated well at all by their boss (section 2.5.2) - are important for the enrichment of one's field of opportunities. Adding to this, trust in a God often contributes to the hope that one can experience (de L'Estoile, 2014).

2.7.4. Human behaviour modelling theory

How individual decision making is modelled is one of the key elements in making an agent-based model. In real life, *"human behaviour is one of the key factors [...] to develop policies to promote more sustainable resource management regimes"* (Pahl-Wostl and Ebenhöh, 2004).

Pahl-Wostl and Ebenhöh (2004) developed an ABM approach using a set of decision heuristics to represent human behaviour. Characterised by nine attributes, the agents devote different levels of importance (from 0 to 1) to cooperativeness, fairness concerning others, conformity, fairness concerning me, positive reciprocity, negative reciprocity, risk aversion, commitment and trustworthiness. The agents also expect a certain level of the importance of attributes that other agents have. In the paper by Pahl-Wostl and Ebenhöh (2004), the agents are assigned with random values for the different attributes, and they expect the same levels that they have with other agents until this is changed by experience. A second learning process concerns the agent's heuristics; a negative experience with one heuristic should lead to the choice of another heuristic in the next similar situation.

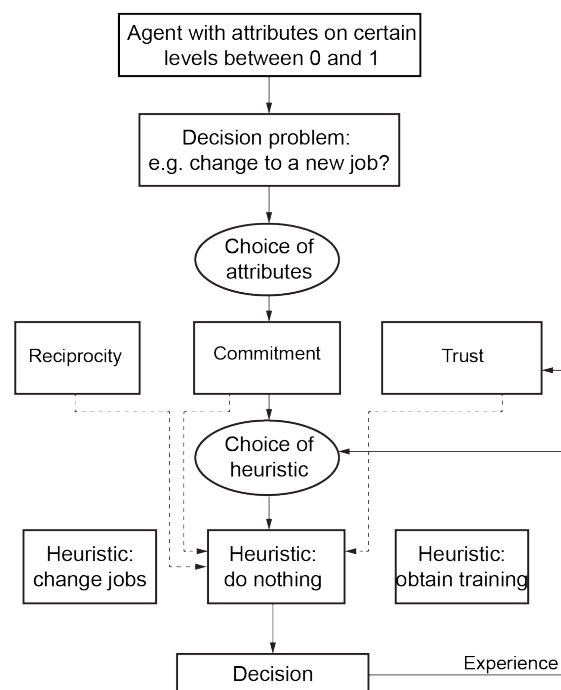


Figure 2.2: Attributes forming the decision making process, adopted from (Pahl-Wostl and Ebenhöh, 2004)

To apply the heuristics to an ABM, Pahl-Wostl and Ebenhöh (2004) recommend differing individual attribute values and the set of heuristics per type of agent and between agents of the same type. *For my case study, the decision problem implies that the most important attributes are commitment and trust of others, while reciprocity is already represented in the "friendship" between workers and their company or workers and their union.* Moreover, the attributes can be used as a variable to investigate how the personality traits of the agents influence the model.

Depending on the agent's attribute values and the agent's expected attributes of others, a heuristic is chosen and a decision is made. For example, a rule can be that more than 0.7 risk aversion means that an agent will decide not to take a big risk, even when the reward is high. An example of a decision matrix applied to the case study is depicted in Figure 2.2.

It should be noted that this method will not actually represent the people in the Norte Fluminense region. Heuristics and attributes in real life are formed by years of experience, culture and social environment; for the model, a lot of assumptions should be made. However, this method provides support for simulating human behaviour, which is one of the key aspects to gain insights into the knowledge gap addressed in this research.

2.8. Sub-conclusion

From the literature review in this chapter, the first research sub-question can be answered: *What is known about how industrial symbiosis influences the (potential) local workforce, and vice versa?*

This thesis aims to gain insights into how an industry's workforce is affected by and affects the revitalisation of that industry through industrial symbiosis, via a case study on the sugar industry workforce in Norte Fluminense. This aim is approached more broadly with the first research sub-question. Therefore, a literature review is conducted on IS and their local workforce. Furthermore, a more specific search is done for comparable cases as reference material for the final results.

The literature that is most comparable with what is sought with regards to IS and their local workforce studies the relationships between managers and key personnel in (developing) ISNs. The insights from these studies that are applicable to the final research question are visualised in figure 2.3. The main social theme is the role of trust in the development of IS exchanges. Doménech and Davies (2011) also couple trust to the community and argue that local support proved to be key in promoting social relationships between initiators of IS exchanges (e.g. the managers of a company in an ISN). For this trust and social relationships to develop, a certain amount of time is needed. Furthermore, it is expected that IS enhances social equity within communities because it provides the need for professional and strong relationships between the involved actors.

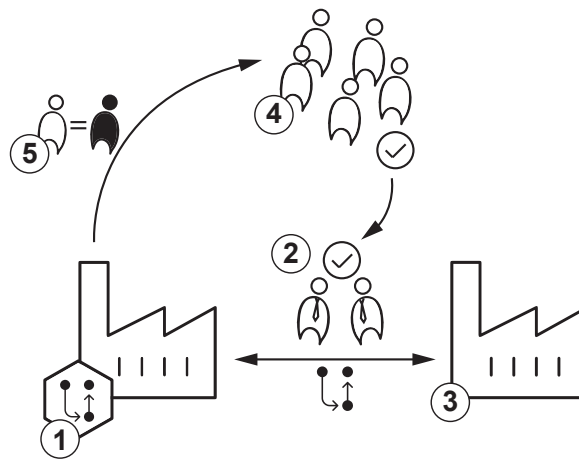


Figure 2.3: The role of trust (2) is essential to a successful relationship between managers of businesses that want to initiate IS exchanges (1) and the approached business for exchange (3). The community, or local workforce (4), can enhance these social relationships. As result of IS exchanges it is expected that the ISN improves the social equity (5) within communities.

The bi-directional effects from IS and their (potential) local workforce are investigated with the few case studies that could be found. The most relevant case is the study from Papong et al. (2017) in Thailand. Papong et al. (2017) showed that bioethanol production employs more people and generates a higher income for the employees compared to conventional gasoline production. The biggest employment contribution (70%) comes from the cultivation of sugarcane. Although these results are perceived as positive for the local workforce, advised is that health and safety training is encouraged throughout the whole supply chain from cassava and sugarcane to bioethanol.

Revitalising an existing industry through industrial symbiosis can result in an increase in well-being and job creation; both of which are considered positive effects for the local community around that industry. However, these effects are measured with only a limited amount of case studies and do not consider the effect of the local community, or workforce, on the industrial symbiosis network.

The literature review revealed and confirmed the large knowledge gap concerning the interaction between IS and its external social dimension. Existing studies often superficially touch on the social side - to include the three pillars of sustainable development - but do not dive deep into, for example, the drivers for a successful realisation of industrial symbiosis with the inclusion of the current local workforce.

The last section of this chapter aims to answer the first model question: *What social theories can be*

used in an agent-based model to make agents socially aware, whilst being relevant for the main research question?

For the studied case, it was identified that there are and have been a lot of power struggles in the sugar industry in Brazil. The life on the plantations in the time of slavery and the life outside the plantations after the land reforms was and is hard for the workers. However, the workers could have a "good" boss or were union member, which both helped them survive. Because of this history and context, the choice is made to use the power and status theory by Kemper (2006) and the theory on the frames of references and fields of opportunities from de L'Estoile (2014). The power and status theory was found from the GRASP theory from Hofstede (2015), which was used as a base for the search for theories. Finally, the wish to represent the workers more realistically resulted in finding the human behaviour modelling theory by Pahl-Wostl and Ebenhöh (2004). Further investigation into the case study resulted in the choice to only use commitment and trust of others as attributes from the human behaviour modelling theory for the agents that represent the workers.

These social theories are of relevance for the main research question because they help simulate the workforce of an industry, in this case, the Norte Fluminense sugar industry. The attempt to represent the people in a workforce more socially aware, and not purely rationally thinking as, for example, the theory of planned behaviour proposes, provides different insights than with conventional ABM theories. Moreover, the applied theories enable the modeller to involve the social world of the agents in the model; for case studies like the one at hand, with a strong, complex historical background, the social world is of great importance. Like de L'Estoile (2014) states, the sugar industry workers cannot be realistically represented by economics, which is often used to represent agents in an ABM.

However, with these theories alone, the ABM could not yet be made. This exact process is elaborated on in the answer to the second model question in chapter 4.

3

Using a social perspective in agent-based modelling

The theories from the last chapter are applied to the case study with the tools that are explained in this chapter. First, in section 3.1, is explained why modelling is used in general, as agent-based modelling is employed as the main tool for investigating the case study. Second, agent-based modelling is elaborated on in section 3.2, which includes argumentation for the use of agent-based modelling specifically. Third and final, section 3.3 describes how the theories from chapter 2 are used for the conceptualisation and formalisation of the model.

3.1. Why modelling?

The thesis takes on a social perspective while investigating the workforce of the industrial symbiosis revitalised industry. In social sciences, traditional research includes qualitative and quantitative methods; respectively analysing individuals through interviews and observations, and statistically analysing patterns of large groups of individuals, mainly through individual measurements. While qualitative research aims to generate insights into the individual's behaviour and internal psychology, quantitative research intends to identify relevant features of amongst others the behaviour and culture of populations. To answer the main research question (chapter 1), both an individual and population approach can be taken; the interaction between an industry and its workforce can be researched through the worker's individual behaviour and through the interaction of the workers and their bosses. However, for both the qualitative and quantitative methods, interaction with the subjects of research is needed. As explained before, this is not achievable due to time, language, and geographical constraints.

When these constraints would be not applicable or somehow overcome, modelling would still be assumed the most logical option for this type of research. Scientific modelling aims to represent real-world phenomena in an objective and rational way; by doing so, models can generally be applied to different cases of the same phenomena. The difference between qualitative and quantitative research and modelling is that, by looking at historical and current measurements, models can be created for future or hypothetical situations like that of the case study at hand. By creating a model based on the relevant individual features of the workers and their environment, and taking into account their individual decision-making, this thesis touches on the individual's behaviour and internal psychology, as well as the behaviour of the population, the workforce as a whole. This way, the research question is approached socially and psychologically and because of the choice for a model, the case study can be generalized to a broader application. Since the aim of this thesis is to investigate the interaction of a workforce and industry revitalised through industrial symbiosis in general, it is believed that modelling is the most logical choice.

3.2. Agent-based modelling

To be able to explore and investigate the interaction between the current sugar industry workforce and the proposed agro-Isn in Norte Fluminense, this system is simulated with agent-based modelling.

Changes and adaptations of agents that are triggered by the development, operation and management of the technological sphere, can be simulated over time. The physical artefacts used for the hypothetical agro-ISN will form that technical network. As the model is built with agents, which Shalizi Rohilla (2006) considers "a thing which does things to things", a schematic overview of those agents in the model is depicted in figure 3.1. Unless cited otherwise, the information in this section is obtained from van Dam et al. (2013).

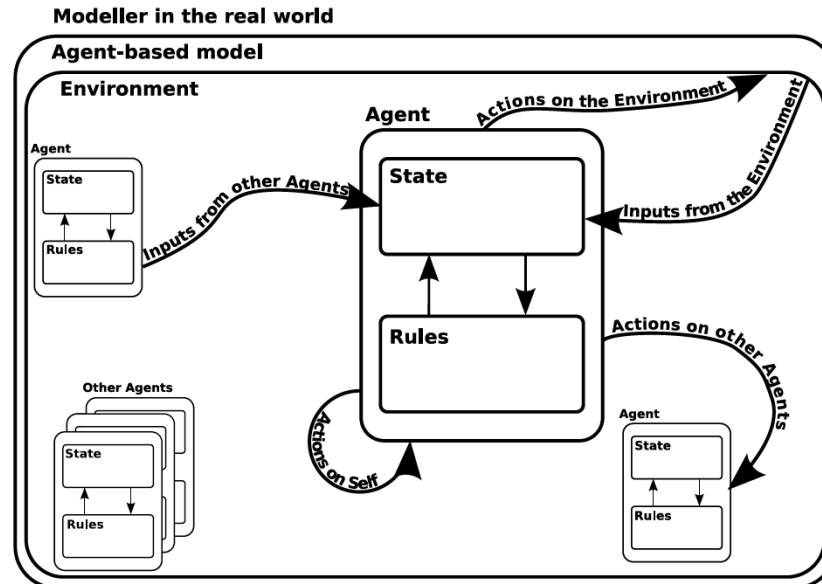


Figure 3.1: Agent-based model structure (van Dam et al., 2013)

As the smallest element of an ABM, **agents** consist of states and rules, hence they are capable to respond to changes and act on those in anticipation. Furthermore, agents are autonomous, can perform actions on itself and others, and anticipate, receive and react on inputs from the environment and other agents. The *state* of an agent is defined by a specific collection of parameters (Wooldridge and Jennings, 1995), and every different part of an agent's state can be made "publicly" known, or "private" and thus not observable by other agents. The state of an agent can be changed by its *rules*, usually based on the assumptions made by the modeller and more specifically can be named decision rules. Types of decision rules include: rule based, multi-criteria decision making, inference engines, evolutionary computing, and machine learning. *Actions* are the "things" that agents do, based on their states influenced by their decision rules. All of the agent's actions and state changes represent the *behaviour* of an agent. The sum of all behaviours of all agents together, including interactions between agents and between agents and the environment, is the emergent property of the modelled system.

Agents are based in a certain **environment**, which provides the structure and space that is needed for the agents to interact. The environment is like a sensor, measuring *time*, agent's parameters, and providing information to the agents. An environment can be structured as a soup, space, small-world network, and scale-free network. These structures can be used singular or multiple, and can be used combined. Since real-world systems exist with a continuous real time, where actions are taking place in parallel, this should also be understood in order to represent them. ABM's take place in the discrete time of computers; this is represented by a 'tick' for each time unit.

3.2.1. 10-step process

This thesis research applies the ABM framework of van Dam et al. (2013). The 10 steps of the framework - that should be used iteratively - are:

1. *Problem formulation and actor identification*: create a well-formulated problem statement.
2. *System identification and decomposition*: define the system boundaries from a CAS perspective.
3. *Concept formalisation*: convert the decomposed system into software data structures.

4. *Model formalisation*: create a model narrative and express in pseudo-code.
5. *Software implementation*: implement the decomposed system and pseudo-code in a programming environment.
6. *Model verification*: analyse if the software implementation corresponds with the conceptual model.
7. *Experimentation*: experiment with the model to provide insights in the problem statement of the first step.
8. *Data analysis*: explore, visualise, interpret and explain data, and look for interesting patterns.
9. *Model validation*: use methods for validation to see whether the model design answers the problem statement.
10. *Model use*: use the results of the previous steps to provide answers to the problem stated in step 1.

ABM is a bottom-up systems approach and stakeholder participation produces greatly valued information (Pahl-Wostl, 2003). However, due to the limited time of this project and the language barrier, all necessary information will be obtained by literature review possibly obtained through collaborative searching in Portuguese together with Ms Santos. Some of the information could only be found in Portuguese, so an online translator tool is used for understanding the literature. With confirmation of Santos of the correctness of the translation, eventually these sources are used as well.

Tools that are used for the implementation of the model and data analysis are respectively Netlogo (Wilensky, 1999) and R (R Core Team, 2013), mainly because of the open source community that supports both of these software tools. This makes them relatively easy to learn and understand on the short term, because of the extensive online help platforms. Furthermore, Netlogo especially is suited for this kind of research since it can easily be used for a proof-of-concept model, like is developed for the case study. R is used as exploration and visualisation tool for the data that is generated with the experiments in Netlogo, and is considered as one of the best statistical visualisation tools available online.

3.2.2. Why agent-based modelling?

The system under research is a so-called "human system" (Bonabeau, 2002) - the workforce in the Norte Fluminense sugar industry are all individuals making decisions in their own, personal way. Other modelling techniques for human systems, or for modelling human decision making, are purely economic or mathematical models, or based on a scenario "what if?" approach which does not provide the opportunity to explore the large range of possible (future) scenarios and outcomes (Wainwright and Mulligan, 2005). ABM is chosen because it can represent the system more realistically than other modelling methods: the individuals in the model can exhibit complex behaviour like learning and adaptation, and the actions of the relevant actors of the system are irrational and thus discontinuous and non linear, which are all features that can be included in an ABM (Bonabeau, 2002).

For the Norte Fluminense case study, and specifically for the social perspective that is used for conceptualisation and formalisation of the model, the features that ABM enables cannot be found in other modelling tools. The external social dimension of an agro-ISN cannot be modelled with rational economic models; if real people are to be represented by a computer model, it is preferred that they can behave irrational. The human behaviour modelling theory by Pahl-Wostl and Ebenhöf (2004) for example, supports irrational behaviour by looking at the characteristics of agents, instead of, for example, following a maximising profit formula. The benefit of using ABM is that theories like these, and the ones that are applied to this case study, can all be combined and formalised into a single model. Furthermore, and what might be the greatest benefit of using ABM, there are no limitations concerning data unavailability, which is the case for this thesis. Therefore, a proof-of-concept can be made, which can serve as a basis for other ABMs that work with more socially aware agents.

3.3. Method

The lack of knowledge on how to create socially intelligent agents (Hofstede, 2015) calls for applying theories that have not yet been used in ABM. Therefore, the method on how to apply theory from chapter 2 to the case study, is explained as the conceptual framework. In the following paragraphs is explained how other approaches, outside of the 10-step ABM process, are applied.

Indicator selection After problem formulation and actor identification (steps 1 and 2 of ABM), a comparison is done between different social indicators via the method of Binder et al. (2013), to pick the most appropriate indicator for job quality. As mentioned in section 2.6, main criteria will be set up and used for an initial selection of indicators found with a literature research of peer-reviewed journals and books. Then, structural criteria for the indicators must be defined. Finally, a choice is made for the most appropriate indicator.

Attention should be paid to other indicators that are not directly derived from literature research. These will only become clear after steps 1 to 4 of the ABM process, because then the system is researched sufficiently to say which indicators are important for the inputs and outputs of the model.

Human behaviour modelling The decision behaviour of the agents is modelled via the heuristics approach of Pahl-Wostl and Ebenhöh (2004). In the first two steps of the ABM process, it becomes clear what type of agents should be modelled, what kind of decisions they are able to make, and what is necessary for them to make those decisions. The decisions are coupled to the most important character attributes relevant to that decision (Pahl-Wostl and Ebenhöh, 2004). As the behaviour of the agents will depend on the value of their attributes, literature review on behaviour of similar groups as the sugar industry workers in Norte Fluminense will enable a decision to assign certain values. Heuristics are made through logical thinking with the literature research of the case study in mind. In these phases of conceptualisation and formalisation, the necessary data is gathered via online sources and if necessary with the help of Santos.

Conceptual framework The application of the theory from chapter 2 to the case study in the first four steps of ABM, is depicted in figure 3.2. This conceptual framework gives an overview of what is applied to which of the following aspects of the agents: their actions, perceptions, states and decisions. A micro and macro level is considered: micro consists of the individuals, while the macro level looks at the society in the system as a whole.

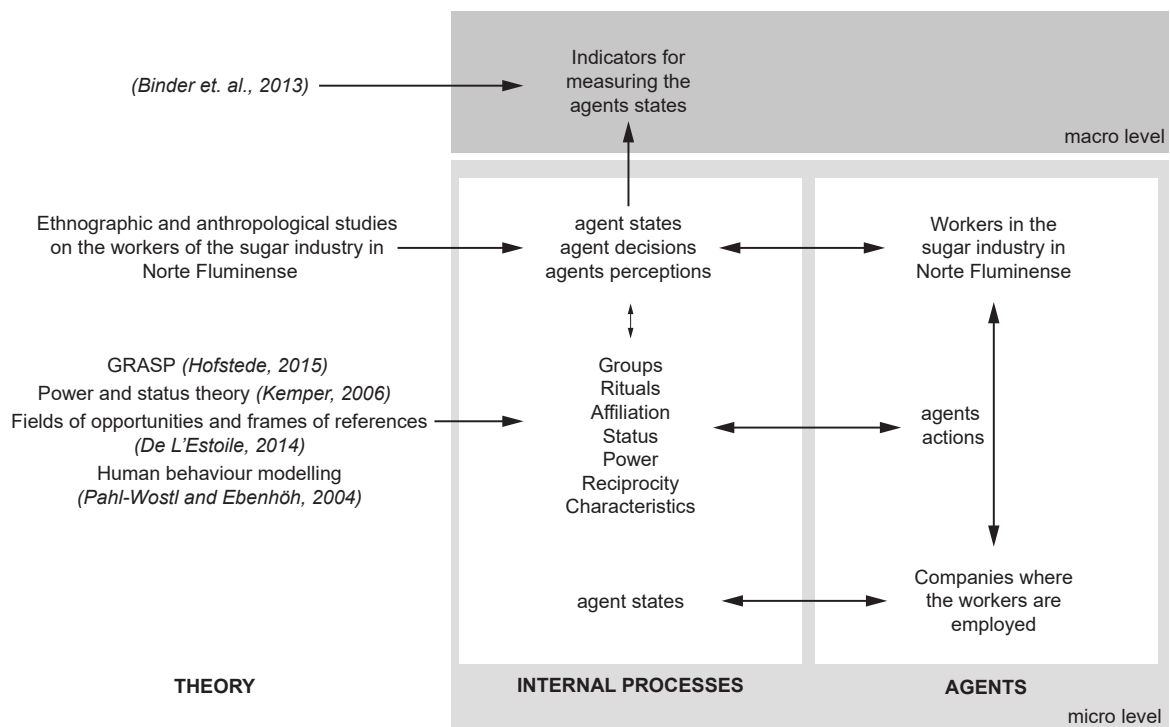


Figure 3.2: Conceptual framework

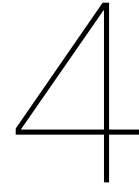
The micro level is divided into the agents and their internal processes, with arrows in between the internal processes and agents to indicate where the chosen actions, perceptions, states and decisions of the agents are derived from. The current two actors, as chosen from the preliminary literature review

from the case study in chapter 2, are the workers in the Norte Fluminense sugar industry, and the companies where the workers are employed at. The sugar industry consists of the sugarcane farms, sugar mills, and other industries related to the sugar industry in Norte Fluminense.

The macro level shows the method for selecting the right indicator for measuring the worker's states. As mentioned before, most indicators are obtained from the model conceptualisation and are thus not picked by applying the method of Binder et al. (2013).

On the left side of figure 3.2, the theory from chapter 2 is linked to the application of that theory at the micro and macro level of the model. The double arrows between the agents and their internal processes can be associated with the theories that are in the same horizontal line. The ethnographic and anthropological studies on the workers of the sugar industry in the region under study are elaborated on in the next chapter, which dives into the conceptualisation of the case study. Also in the next chapter, the agent groups, or types, actions, states, decisions and perceptions are explained.

After the system identification and decomposition, the third until the tenth step are followed according to the ABM 10-step process (van Dam et al., 2013). Thereafter, the results are evaluated with the current knowledge of case studies and findings done throughout the research. Insights will provide a beginning of an understanding of the knowledge gap presented in chapter 1.



Conceptualising the world of the sugar industry workforce

In this chapter, the world of the sugar industry workers - as perceived from literature - is conceptualised with the first two steps of agent-based modelling. Section 4.1 elaborates on problem formulation and actor identification and in section 4.2 the system is identified and decomposed. This is called the model conceptualisation, which is formalised into a proof-of-concept model in chapter 5. The chapter is finalised with the conclusion that answers the second model question.

4.1. Problems and relevant actors

Problem The problem that is addressed in this agent-based model is the lack of insight in how the Norte Fluminense sugar industry workforce is affected by and affects the proposed agro-ISN in terms of (lack of) employment, skill level and job quality. The agents that are most relevant in this aspect are the current sugar industry employees (workers), the companies they work in, and the workers union in Norte Fluminense. The timespan that is addressed is from 1999 to 2040, because of collaboration with Ms Santos and the availability of historical data.

A two-way focus is used: (1) from individual to society (social and socio-psychological), and (2) from society to the individual (macroeconomic). The first point of focus is on human decision-making processes influenced by their relevant characteristics, the relationships between the different agents, and their resulting actions from those character traits and relations. The second point focuses on the external market effects on the employers and their decision to hire or fire someone, and the effect of hiring and requalification subsidies.

Emergent patterns The combination of the sugar industry that is in decline, the violation of good labour conditions by sugar supply chain companies and the low education level of the sugar industry workforce brings us to the following *observed emergent pattern of interest*: the sugar industry workers are 'trapped' in their jobs (Chase, 1999) and do not have the opportunity to obtain a better job, which is defined by the job quality and skill level required for that job.

It is proposed by Santos to revitalise the sugar industry in the long term with an agro-ISN. For the exploration of different configurations of subsidies and social attributes, two main scenarios are chosen in which the only differences are the number and type of companies:

- The *reference scenario* of the current situation: with sugarcane farms, and sugar and ethanol producing mills; no subsidies are supplied for hiring or requalification.
- The *proposed scenario*: with sugarcane farms, sugar and ethanol producing mills, and other industries (adhesive manufacturers, effluent treatment and biogas production plants, and cosmetic wax producers), and in 2013 also biorefineries; subsidies can be supplied in different fashions for hiring and requalification.

Initial hypothesis In the proposed scenario, the *desired emergent pattern of interest*, or initial hypothesis, is that the workers are able, and will to switch to a better job, again defined by the job quality and skill level. Furthermore, it is expected that the overall job quality of the employed jobs rises, the agro-ISN is able to fill their jobs with locals and the worker's perception of their own status and power increases.

This is the kind of emergence *imposed by rules* that force the model to produce these results. However, this desired outcome is then influenced by the social interactions between all agents and characteristics of the workers. This is the mechanistic representation of the *adaptive behaviour* of individuals.

Whose problem are we addressing? The targeted decision-makers are the policymakers responsible for the proposed agro-ISN. Questions that can be asked in this regard are: should we promote this proposed agro-ISN with requalification and hiring subsidies, and if so, how do the social interactions between the workers, union and companies and worker characteristics influence the foreseen outcomes?

The second targeted decision-makers are the companies. In the model, they are not able to make decisions like the policy makers aforementioned but their decisions are already made for them. Therefore, a short explanation of the questions that they could have in this regard is given.

Questions that can be posed by the companies are: how do we benefit from providing a better job quality for the workers, and why would we prefer to hire local people from the current sugar industry? The first part of the question can be answered theoretically by consulting Diener and Seligman (2004), in their research towards an economy of well-being. Here, they state that employees who experience a high level of well-being have a better working performance than employees who experience a low state of well-being. This includes helping colleagues at work in various ways and having better social relationships in general. The level of well-being is less frequently coupled to income, and more commonly determined by work satisfaction and social relationships (Diener and Seligman, 2004).

About the second part of the question, local growth has significant positive effects on labour markets (Bartik, 1991). A sudden job increase allows the local workers to develop their employment experience, which improves their long-term market success. This can be perceived as beneficial for the companies because of the availability of adequately skilled workers for their vacant jobs.

Agents There are three types of agents in this system. The sugar industry workers, initially working at sugarcane farms, sugar mills and other industries currently in the sugar industry in the region. In a later stage, they can be potentially working at the biorefineries and other industries involved in the ISN, the latter which are producing adhesives, biogas, cosmetic wax, and treating effluent. The second type of agents are the companies where these workers are employed. The third agent type is the union in Norte Fluminense: SISERJ.

Our role As the modeller, my role is to explore the possibilities of an ABM to simulate more realistic agents by involving social and psychological aspects, concerning the case study.

4.2. The system - decomposed

The world of the sugar industry workers, from now on simply called the *workers*, exists mainly around the place where they work: in the settlements or towns around the farms or mills. Labour on the farms can be manual or mechanized, as is decided by the farm. A typical sugar industry worker is male, 18 - 25 years old, has received education for 0 - 4 years when working manually on the farms or 8 - 11 years of education when operating mechanized harvesters, and is most likely a seasonal and/or migrant worker (Rocha et al., 2010). The two parties that are most influencing their employment, skill level and job quality, are the *companies* the workers are (potentially) employed in, and the *union* that continuously strives for improvements in labour regulations or so-called "rights" of the workers (Sigaud, 2008). There is only one sugar industry workers' union in Norte Fluminense: SISERJ, Sindicato da Indústria Sucreenergética do Estado do Rio de Janeiro, or Sugarcane Industry Union of Rio de Janeiro State.

Throughout history, the exercise of power of the sugarcane farms and mills owners have dominated the lives of the workers (Sigaud, 2008). As former slaves, or *moradores*, the workers lived and worked

on the farms that initially also produced sugar. Later, the production of sugar was centralized in *usinas* (sugar mills), which resulted in a relative loss of power of the farm owners (Sigaud, 2008). At this time, more rights were obtained for the sugar workers, and to avoid to comply with those new regulations, some workers were sent away from the farm to live in towns nearby. In most of these cases, the workers continued to work on the same plantation as *clandestinos*, still, or now without any formal contract (Sigaud, 2008). Another method for the companies to avoid regulations, and which often was associated with slave-like labour conditions, was to hire *gatos* (Coslovsky and Locke, 2013). They are middlemen for recruiting workers, who provide the right amount of workforce on demand. However, this practice was banned under the National Commitment, an agreement between companies and unions, and thus will not be taken into account.

The words that are used in the daily lives of the workers are analogous to the past: *cativeiro* (captivity), used to describe the contemporary work conditions on the farms; *liberto* (free), used to describe the worker's feeling when they could live in a town; and *cativo* (captive), which means "designated unconditional submission to the boss", all remember the time slavery officially existed (Sigaud, 2008). The current, still existing big differences in power and in enacting power are nowadays investigated by amongst others private auditors and inspectors of labour conditions. For the simplicity of this model, this control is performed by the union by having workers report their complaints to them.

The outline of the sugar industry sector transforming to an agro-ISM was established by applying theories for social interactions between the workers, companies and union that lead to the decision making of those workers. The big differences in power and status are used for representing the social interactions of the agents in this model, explained in section 4.2.1 as their perceptions. To make the model more realistic, the commitment and trust of the workers are included to influence the choices that they can make, these are elaborated as their characteristics. The two other agent types in the model are the companies and the union, respectively explained in section 4.2.2 and 4.2.3. Furthermore, the concept of a job and training is described in section 4.2.4. All possible interactions between the agents and thus the choices they are able to make are elaborated in section 4.2.5. The policy instruments that will be tested and the criteria that measure the outcomes of the model are explained in section 4.2.6. The environment where the agents exist in and its external variables are outlined in section 4.2.7.

4.2.1. Workers

Perceptions - group identity, affiliations, power and status All agents have perceptions of their own and other's power and status, which can be insufficient, adequate, or excessive. In the current situation, these perceptions are as shown for the power and status respectively in Table 4.1 and 4.2.

Table 4.1: Initial power perceptions of the agents

Power			
	other		
self	workers	companies	union
workers	insufficient	excessive	insufficient
companies	adequate	adequate	excessive
union	insufficient	excessive	insufficient

The perceived own power and status of the workers and the union is insufficient; the workers find they do not receive enough respect from their company, who makes them work hard for little benefits. Furthermore, the workers do not have the power to make the others comply with their wishes, such as receiving a piece of land where they can work on themselves at the moment they want to (Sigaud, 2008). The union initially has no influence over the companies and thus feels a power deficit; the union's status is insufficient because they do not get any attention from either the workers or companies. The workers and union perceive the company's power and status as excessive, because of the same reasons their own power and status are insufficient. The companies think their own power and status are of adequate level, as they choose not to act on the power and status deficit that the workers perceive of themselves.

As explained in section 2.7.1, a status deficit causes agents to obtain *formal attainment according*

Table 4.2: Initial status perceptions of the agents

Status			
	other		
self	workers	companies	union
workers	insufficient	adequate	adequate
companies	adequate	adequate	excessive
union	insufficient	excessive	insufficient

to *universalistic criteria* or to *appeal to norms of justice*. A power deficit provokes agents to *reduce their dependency* of the one with excessive power, or to *build a coalition*. These actions are explained in section 4.2.5. Through these actions, the power and status relationships can change: with each interaction, one's power and status can remain the same, increase, or decrease.

The emotions resulting from a certain power-status relationship are explained in section 2.7.2. These emotions can be used to indicate how the agents feel in the particular situation they are in.

Other types of perceptions that the agents are experiencing are the perception of friendship, which is related to reciprocity, their field of opportunities and frames of reference. Workers can be "friends", as explained by de L'Estoile (2014), with either the company they work at or the union. As explained in section 2.7.3, the friends determine largely the fields of opportunities; the union gives opportunities to improve work conditions and to acquire skills, while companies provide better job opportunities.

Characteristics The most important attributes of the human behaviour modelling theory of Pahl-Wostl and Ebenhöh (2004) (section 2.7.4) are chosen on the basis of the worker's decision problems. The decision problems of the other agents, the companies and the union, require a different kind of incentive and have a much more straightforward method of decision. The companies, for example, need enough employees and only comply with more regulations when they are forced to. The union has the goal to obtain the best labour conditions for the workers as possible and will make every decision based on this. Because the workers have to make choices concerning their employment - see section 4.2.5 for the actions they can perform - commitment and trust of others are thought to be the most important attributes. The workers will have a level of 0.0 - 1.0 in terms of these attributes, and on the basis of the heuristics that are developed in the formalisation phase (chapter 5), choices will be made for the levels of these attributes.

4.2.2. Companies

Companies can be a sugarcane farm, sugar mill, biorefinery or other industry; the latter is a collective name for companies that are already a part of the sugar industry in Norte Fluminense or are in a later stage founded as an addition to the agro-LSN. The company agents include their decision-makers like managers and owners, and thus all decisions are made by the company itself. Each company has a certain number of jobs that can be filled by employees, if the job is not filled, it is considered as a vacancy. More on the concept of jobs is explained in section 4.2.4.

Interaction with the technical model The only factors from Santos' technical model influencing this social model are the number of companies over time and the number of jobs at each company, which is a set number for the whole time period. From 1999 to 2013, the number of mills goes from 9 to 3, which is obtained by Santos from historical data. The number of farms stays the same throughout the time of the model; from historical data, there are 5500 farms, but this number is reduced to 550 to improve the computation time of the model. The number of jobs per company is also determined by Santos, and obtained from historical data and computed by the processing capacity of the companies.

The interaction of this thesis' model with the technical model includes the productivity of the companies, which is in turn influenced by the number of jobs that are employed at that company and by the occasion of a strike. More vacancies result in a lower productivity; a strike also lowers the productivity. The final productivity is translated into the processing capacity of the companies in Santos' model.

4.2.3. Union

There is one agent of the union type; which represents the only union for the sugar industry in Norte Fluminense: SISERJ. The agent includes all decision making of the union. The rate of workers that is union member could not easily be found because the search had to be conducted in Portuguese. However, the unionised rate of workers was determined at 37%, as guestimate of a compilation of information (Arbache, 2008, e.g.). Afterwards, a number of (trade) unions of the sugar and alcohol industry in Brazil were contacted via email: SISERJ, SINDAÇUCAR, ALCOPAR, FERAESP, amongst others. Although the unions responded, different numbers for different years were found in the sent and recommended literature for the union membership rate in the sugar industry in 1999. Therefore, the unionised rate of the workers is kept at 37%.

4.2.4. The concept of a job and training

The world of the sugar industry workers contains two types of concepts: jobs and training. The companies have jobs which can be occupied by workers if they are adequately qualified; workers can be either employed when they have a job or are otherwise unemployed. When subsidised by the government, requalification training, or simply job training, is organised by the union. These two concepts are explained in the following paragraphs.

Job concept Jobs can belong to different types of companies and are different per type of company. A job is defined by the skills that are required for that job and the resources and demands the company chooses to supply to or require from the workers. It is assumed that each company only has one kind of job for their employees; i.e. all the jobs at the mill require the same skill and have the same resources and demands.

The resources and demands of a job are used to measure the incidence of *job strain*, which in turn is one of the three dimensions of *job quality* by the OECD (2014). The composite indicator of job strain, which means the workers face a situation with more job demands than the number of resources they have at their disposal, is depicted in figure 4.1. If job strain is experienced, it can be a measurement of the number of jobs that are harmful to one's health. This indicator is chosen according to the method explained in chapter 3; an overview of the main criteria used and an initial selection of indicators can be found in appendix A.

Job strain, as the result of ...	
... too many job demands	... and too few job resources
Time pressure <ul style="list-style-type: none"> - Work usually more than 50 hours per week - Difficult to take an hour or two off during working hours for personal or family matters - Work at very high speed and to tight deadlines 	Work autonomy and learning opportunities <ul style="list-style-type: none"> - Can choose or change the order of tasks - Can choose or change methods of work - Job involves learning new things - Employer provided training or on-the-job training
Physical health risk factors <ul style="list-style-type: none"> - Tiring and painful positions - Carrying or moving heavy loads - Exposed to vibrations from hand tools, machinery - Exposure to high noise - Exposure to high or low temperature 	Good workplace relationships <ul style="list-style-type: none"> - Feel "at home" at work and have very good friends at work

Figure 4.1: Job quality (OECD, 2014)

Training concept A successful method for requalification of the sugar industry workforce is the Program for Retraining Sugarcane Workers, or RenovAcção (UNICA, 2010). This program was organised by the Brazilian Sugarcane Industry Association (UNICA), the Federation of Salaried Employees of the State of São Paulo (FERAESP) and supply-chain companies, and financially supported by the Inter-American Development Bank (IDB). RenovAcção was initiated because of the mechanisation of sugarcane production; for each harvesting machine, 80 employees are replaced. Two types of retraining were organised: for positions in the mechanized sugarcane farm, and for work in other agricultural services and in the industrial and urban sector. The training programs are designed in a way that the workers continue to earn wages, to ensure they participate in all the lessons and workshops.

For the case study, training is conceptualised with RenovAcção as an example, potentially funded by governmental or other institutions - which is not defined because it lies outside this thesis' scope. Similar is that workers can participate in a training program whilst having a job, and it is assumed that the trainings, which are for obtaining general skills for the agro-LSN supply chain, are successfully completed by every worker. The program can only be initiated when the union receives subsidies. Because the subsidies are specifically aimed at requalifying the workers in the current sugar industry for the proposed agro-LSN, no subsidies will be provided in the reference scenario.

4.2.5. Interactions - rituals

All internal processes and interactions shape the worker's fields of opportunities; this occurs in the 'mind' of the agent. The following actions of the workers can be seen as the typical rituals that are performed to act on status or power deficit.

Social interactions The social interactions between companies, workers and unions give the workers a perception of the power and status of his or her self. As mentioned before, the agents start with a **perception** of themselves. Over time, the agents exercise power on and confer status to other agents which changes their perceptions. Furthermore, actions that are perceived as status rewarding can lead to "*friendship*" between the actor that received the status conferral, and the actor who conferred status.

Internal processes Inside the 'mind' of the workers, or their unconsciousness, workers have a perception of their own level of power and status. Every tick, this is **updated** with help from a **memory**: the workers remember if they have been hired, for example.

Actions and interactions The worker's fields of *opportunities* are defined by their perception of their own status and power. When workers perceive a status deficit, they can act on this by **joining a strike** (normative appeal) or **applying for training** (formal attainment according to universalistic criteria). A power deficit is acted on by **applying for a new job** (dependency reduction) or **joining the union** (coalition-building) (Kemper, 2006). Depending on their deficit of status and/or power, different opportunities present themselves. With the help of heuristics and thus the workers' level of commitment and trust of others, the workers are able to make a decision on which action to take, as explained in chapter 5. Trust of others is further on simply called trust.

Further actions of the workers include the possibility to **report** complaints about their job quality to the union. The companies have the possibility to **hire** or **fire** workers. The union can **negotiate** with the companies about the quality of the workers' jobs, and are able to **requalify** workers when they receive requalification subsidies.

4.2.6. Policy instruments and criteria

The input and output of the system are respectively the policy instruments and criteria that are tested to explore the options of this proof-of-concept model. One of the policy instruments already mentioned is *subsidising* the union for a *requalification* program, the other instrument is *subsidising* the companies to be able to *hire* from a bigger range of workers in terms of skill level.

The criteria that are used to measure the effects of the policy instruments are the *vacancies* (the percentage of jobs that are not filled), the *unemployment* (the percentage of workers without a job), the *job quality* (the percentage of the incidence of job strain), the *average skill level*, and the number of workers that feel a *status* and *power deficit*, or are satisfied with their status or power (adequate level of status and power).

4.2.7. Environment

The environment where the workers, companies and union exist in is determined by variables from Santos' model: the number and type of companies, for the farms and mills from historical data, the number of jobs per company, and the market forces which can make companies go bankrupt or start operating again. Furthermore, the environment enables all the interactions between the companies, the union and the workers.

From the environment and the actions of the agents is concluded that the most logical time step is one year or one harvest season. This is the same for Santos model and seems realistic since

actions include applying for a job and obtaining training for the workers, hiring for the companies, and negotiating for the union. These actions take time and are most likely to happen within one year.

The system, its decision-makers and their instruments to reach their objectives measured by the criteria, the other stakeholders, and external variables are shown in figure 4.2. This diagram represents the visual conclusion of the system identification and decomposition.

4.3. Sub-conclusion

Answered with insights from chapter 3 and the current chapter is the second model question: *How are the social behaviour models or social theories applied in the case study?*

The 10-step ABM process involves a system identification and decomposition step, in which the Norte Fluminense case is investigated thoroughly with anthropological and ethnographic studies. All relevant aspects involving the employment of the sugar industry workers are tried to be touched on and decomposed into useful agents, objects, states, actions and interactions for the model. The theories as explained in chapter 2 are applied throughout the identification and decomposition of the system. For all the identified relevant (inter)actions that occurred in the history of the sugar industry workers, a connection is made with the theories. For example, the power and status theory argues that there are certain actions one can take when they perceive a power or status deficit (Kemper, 2006). Since the theory explains clearly when people feel such a power or status deficit, this is identified for the agents under research. In addition, there are plenty actions one could take to increase their perception of their own power or status as elaborated by Kemper (2006), and they are easily relatable to the case study.

The theory of frames of references and fields of opportunities was by de L'Estoile (2014) derived from studying a very comparable case in Brazil. Therefore, this theory was by definition already applied to, at least, a very similar case study. However, conceptualising the theory into a valuable proof-of-concept for the case study required combining the theory with the actions for obtaining adequate power and status. The frames of reference of the sugarcane plantations were used from the theory of de L'Estoile (2014), in which is explained that the workers can be either "friends" with their boss or their union. This influences the status and power acquiring actions one can take, which are seen in this model as the worker's fields of opportunities, partly enabled by the "friends" they have.

Finally, the human behaviour modelling theory of Pahl-Wostl and Ebenhöh (2004) is applied in the conceptualisation of the system. The theory identifies nine different attributes a person can have for themselves and about others: cooperativeness, fairness concerning others, conformity, fairness concerning me, positive reciprocity, negative reciprocity, risk aversion, commitment and trustworthiness. From these the most important and most applicable two are chosen: commitment and trust of others, the latter which is the trustworthiness of other people. These two were perceived as the most influencing attributes the sugar industry worker can have regarding their choice of action that is within their field of opportunities. Trust is mainly chosen because the desired emergent pattern of the model is that the workers have the ability to switch to a better job, defined by job quality and skill level. Trust is needed for people to make a big change in their life, like changing jobs. Commitment is chosen because the workers may have a certain degree of commitment towards their "good" bosses, and may not be willing to give up their loyalty in return for what is here defined as a better job.

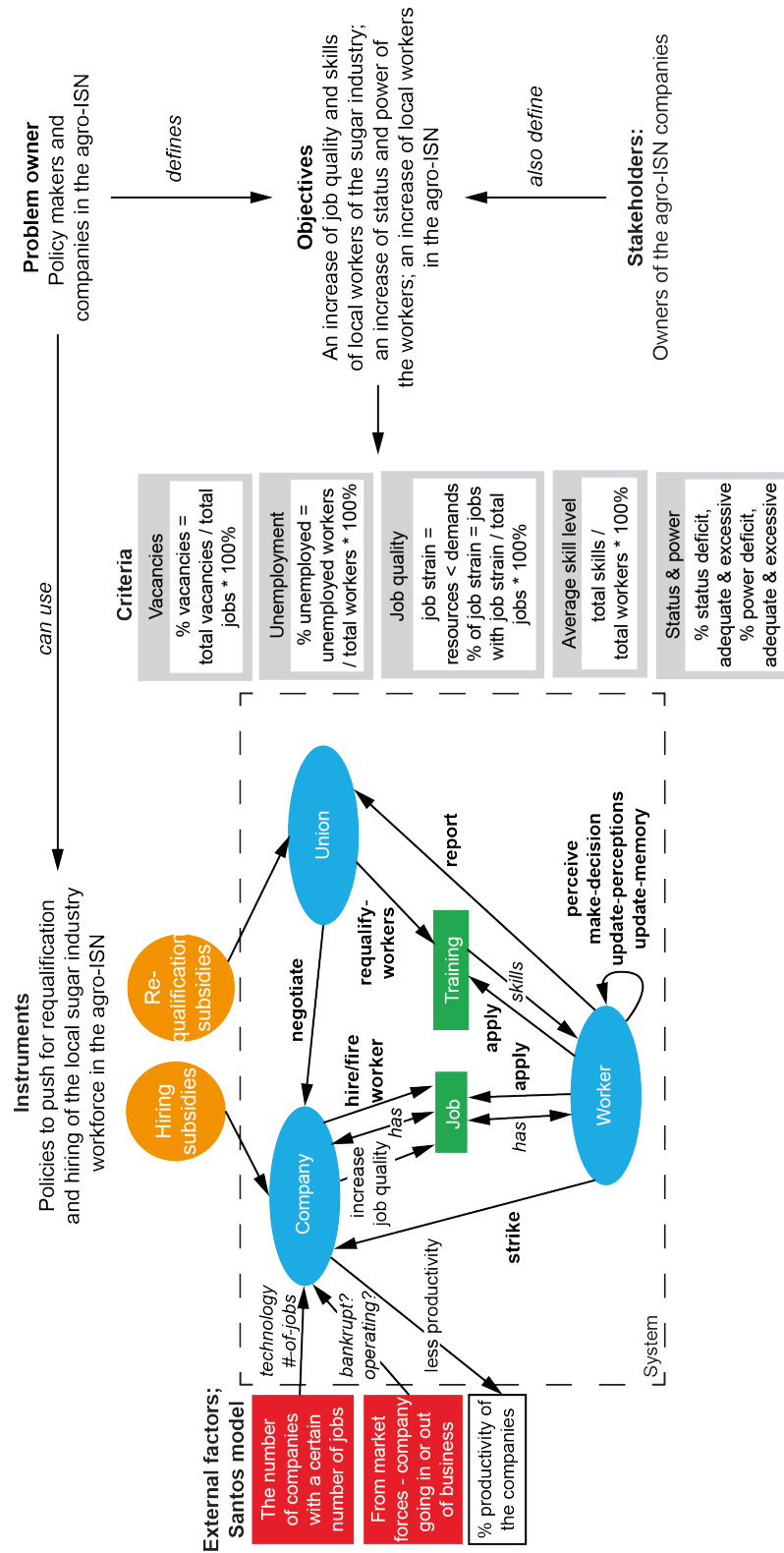


Figure 4.2: System diagram

5

Model implementation

Even though so much is yet undiscovered on the subject of modelling socially intelligent agents, the choice is made to go beyond the conceptualisation phase and to formalise and implement the model. Model implementation enables exploration of the concept; it provides material for a proof-of-concept. This chapter consist of the formalisation of the concept (section 5.1) and model (section 5.2). The implementation of the model into Netlogo is briefly elaborated on in section 5.3. Thereafter, it is verified in section 5.4 that the model does what it is intended to do. This chapter is concluded by answering the second research sub-question in section 5.5.

As with most ABMs, the purpose of this model is not to perfectly describe reality but to better understand the interactions and the possible scenarios. To be able to do so, a lot of assumptions have been made to design the system into one that is understandable by the software used. The full list of assumptions can be found in appendix B.

5.1. Formalising socially aware agents

The concept must be formalised into data structures that the Netlogo software can understand. All the states of the agents and objects, and which value they can have, can be found in appendix C. All states and actions of the agents and the states of the objects are respectively shown in figures 5.1 and 5.2. The full overview of states and actions of the model can be found in appendix D. For the most important state variables and the non-obvious ones is explained in the following paragraphs why they are formalised as such. In the following sections, the (inter)actions of agents are written in a **bold** font, and the states of the agents or objects are written in *italic* font.

Floats Floats are numbers with decimals, and the following states of the agents and/or objects are formalised as such. *Skills* are measured on a scale from 0.01 to 1.00; all jobs are the same per company, and with the requalification training the workers can obtain general skills, applicable for all jobs in the agro-ISN. This formalisation allows compatibility for all jobs and provides a big enough range for measuring differences in skill levels. The skills are also variables for the training - the *skills* that are *added*; and for the jobs - the *skills* that are *required* for that job. An important assumption here is that all jobs are the same per company type (appendix B, assumption 7).

Status and *power* is measured on a scale from -1.0 to 1.0, with steps of 0.1. The negative values represent a status or power deficit at the point of a deficit threshold, and above that threshold an adequate level of status or power (appendix B, assumption 11). Each worker can gain or lose status and power each year, how much is determined by input variables. The mechanisms that determine when workers lose or gain status and power are explained in section 5.2; with these mechanisms is simulated that changes do not occur within only a few years, as described in the literature on the history of the sugar industry in Brazil. As explained before in chapter 4, the level of *commitment* and *trust of others* of the workers is a random number between 0.0 and 1.0; Pahl-Wostl and Ebenhöh (2004) recommend this type of formalisation, as well as assigning a high and low level to the attributes.

Agents

Workers	Companies	Union
states	states	states
<i>skills [float]</i> <i>status [float]</i> <i>power [float]</i> <i>commitment [float]</i> <i>trust-of-others [float]</i> <i>company-friend? [boolean]</i> <i>union-friend? [boolean]</i> <i>join-strike? [boolean]</i> <i>opportunities [list]</i> <i>demands-last [integer]</i> <i>resources-last [integer]</i> <i>demands-now [integer]</i> <i>resources-now [integer]</i> <i>skills-last [float]</i> <i>number [integer]</i> <i>fired? [boolean]</i> <i>hired? [boolean]</i> <i>apply-training [boolean]</i> <i>job [object]</i> <i>training [object]</i>	<i>technology [string]</i> <i>strikes [integer]</i> <i>productivity [integer]</i> <i>vacancies [integer]</i> <i>bankrupt? [boolean]</i> <i>operating? [boolean]</i> <i>jobs [object]</i>	<i>current-resources [integer]</i> <i>current-demands [integer]</i> <i>desired-resources [integer]</i> <i>desired-demands [integer]</i> <i>complaints [integer]</i> <i>negotiation [integer]</i> <i>trainings [integer]</i> <i>training [object]</i>
actions	actions	actions
perceive make-decision update-perceptions update-memory apply report	hire fire	requalify-workers negotiate

Figure 5.1: States and actions of the worker, company and union agents

Objects

Jobs	Training
states	states
<i>skills-required [float]</i> <i>resources [integer]</i> <i>demands [integer]</i> <i>employee [integer]</i> <i>applicant? [number of agent]</i>	<i>trainee [number of agent]</i> <i>skill-added [float]</i>

Figure 5.2: States of the objects

For this again, thresholds are made for the high and low levels of the worker's attributes (appendix B, assumption 23).

Integers Integers are whole numbers, in the model used for counting the number of an occurrence of something: for the companies the *strikes* they have had and their number of *vacancies*, for the union the *complaints* they receive from the workers and the times they have been in *negotiation* with the companies.

The *resources* and *demands* of the jobs are variables of the jobs but are also measured by the union (current and desired), and by the worker (from the current year and the year before that). These are all formalised as levels of 0, 1, or 2. The 0 for the resources can be seen as no work autonomy and no learning opportunities, 1 represents that there is work autonomy in the job, and 2 means work autonomy and learning opportunities available. The measure of good workplace relationships is left out: this cannot be guestimated with the literature that is available. With 0 demands, the job does apply time pressure or physical health risks on the workers, 1 demand means that the workers that occupy that job do experience time pressure, and 2 demands add the physical health risks to the time pressure that workers experience.

Booleans Almost all the other variables are booleans: these are always either true (yes) or false (no). For example, when a worker is a member of the union, then the variable *company-friend?* is true.

5.2. Model narratives

The general actions the agents in this model undertake are depicted in the flowcharts in figure 5.3. The actions per agent are explained as model narratives in the following paragraphs, and all of the flowcharts for all specific actions can be found in appendix E.

Workers Workers start with **perceiving** their level of status and power, which results in a combination of a few or all of the following *opportunities*: apply for training, apply for a job, strike, or join the union. These opportunities can be seen as a list of actions they want to undertake to increase their status and power. When the workers feel their status and power are adequate or excessive, and they are no *friends*, or member, of the union, they become friends with their company. Next, the workers **make a decision** on what action they are going to undertake, based on whether they are friends with the union, friends with their company, or friends with no one, their level of *commitment* and *trust of others*, and the *resources* and *demands* of their job.

All the different pathways that workers can follow depending on the before-mentioned variables, are modelled as heuristics (Pahl-Wostl and Ebenhöf, 2004). The worker can only act if the chosen action is in their list of opportunities, otherwise, he or she continues with the same as before, i.e. no action is undertaken. When the agent applies for a job or training, the respective company or union decides whether the agent is hired or not, or if they are accepted for the training or not. Workers can only apply for jobs that require the same or lower level of skills as they have. Workers that are friends with the union and have less resources than demands in their current job, have the chance to **report** their complaints to the union. When more than 50% of the workers of a certain company want to join a strike, the strike is initiated and the company does not operate or produce anything for one year. This 50% mark is an assumed value, derived from experimentation with the model with the aim to most realistically represent the timing of the strikes.

At the end of action-sequence of the workers, their **perceptions** are **updated** according to a comparison of the demands and resources of their last job and current job, the skills they potentially gained, and whether they have been hired or fired in that year. Finally, their **memory** is **updated**, which consists of their skills, demands and resources of the current year and the year before that.

Companies Companies try to fill all of their vacancies by **hiring** workers, but are only able to do so if agents are applying (appendix B, assumptions 2, 20 and 21). When a company cannot find anyone for a job, it stays vacant, and the company's *productivity* declines. The *productivity* of a company is defined by the number of occupied jobs times the skill level required for those jobs, times the *productivity weighing* for the specific company type (appendix B, assumption 6). A 100% *productivity* is reached

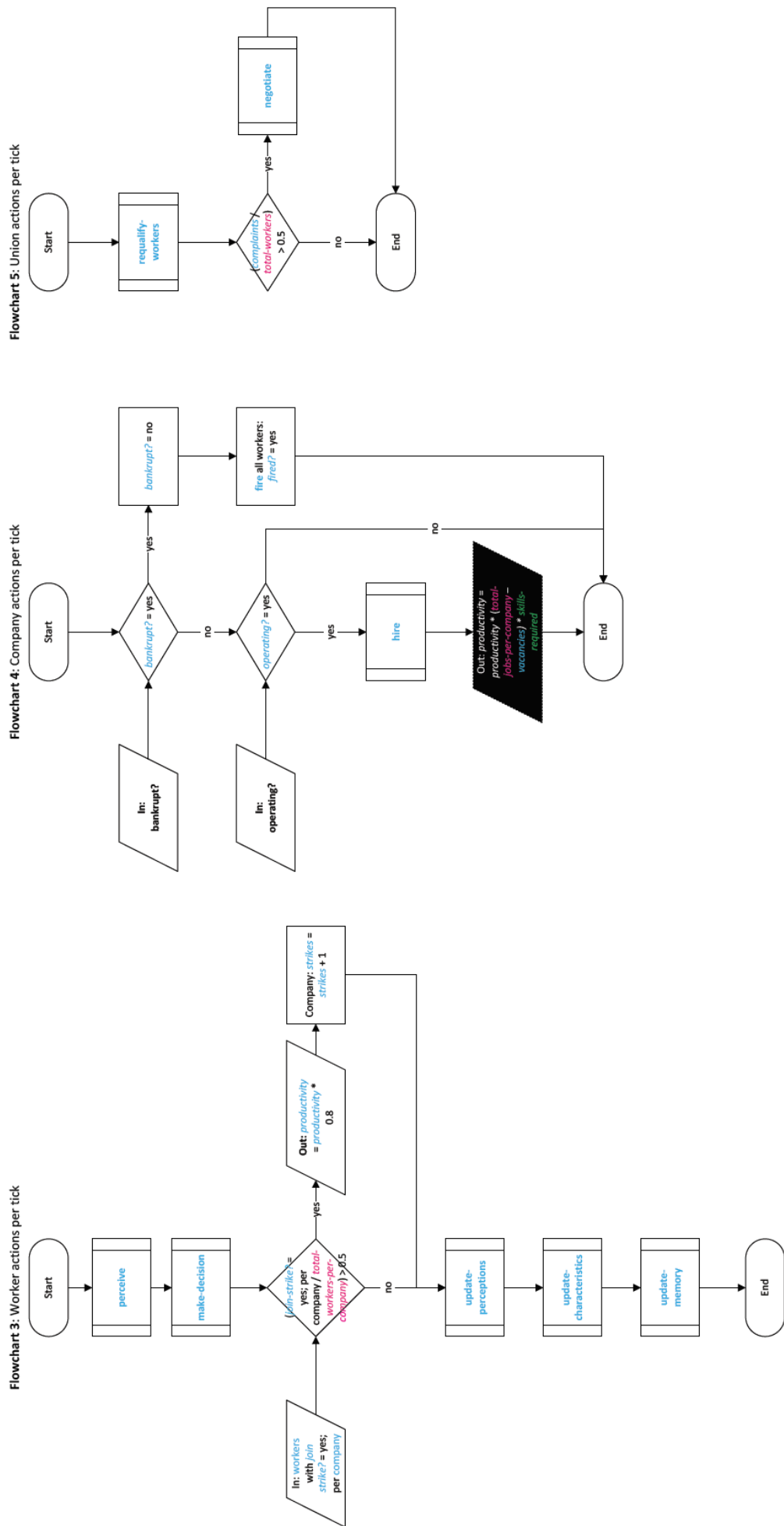


Figure 5.3: General actions of the agents

when all jobs in the company are occupied, from this and the skill level required for those jobs, the *productivity weighing* has been calculated.

Hiring subsidies can help fill the vacancies (appendix B, assumption 17). The number of jobs that a company can fill with the hiring subsidies is calculated by the percentage hiring subsidies times the total jobs at that company. Now, the company has an increased range (10%, an assumption) of who they can hire, which means that the company can even hire workers with a slightly insufficient skill level. The worker's skill level will increase by being hired with hiring subsidies; he or she learns on-the-job.

Market forces from Santos' technical model, here the external variables, influence when a company goes bankrupt. In this occasion, all employees are **fired**. The same market forces can determine if a company starts operating again, which would mean that it has to try to hire workers for all their jobs.

Union Without any *subsidies for requalification* of the workers in the farms and mills, the union only keeps track of the complaints that are reported by the workers. When more than 50% of the workers have reported complaints, they start **negotiating** with the companies. This threshold of 50% is based on try-outs with the model, after which this percentage is chosen because it seemed to take an adequate time before the union starts negotiations. Firstly, the union tries to lower the demands of the jobs for each company. The company complies with lowering the demand with one level if they experienced at least one strike. The second time there are more than 50% of the workers reporting complaints - this number is reset after negotiation - the union demands that the resources of the jobs of each company are increased. Again, the company will comply with increasing the resources with one level if they experienced at least 2 strikes. The third time, the union tries to decrease the demands again and the fourth time to increase the resources.

With *requalification* subsidies, the union can organise *trainings* where workers can increase their skills. The number of *trainings* the union can supply is the percentage of subsidies times the total number of farms and mills jobs. Workers go to *training* while they have a job.

5.3. Model implementation

The model is programmed in Netlogo, see the SVN server for the full model code¹.

5.4. Verification

Multiple checks and tests are performed to see whether the model does what it was intended to do according to the conceptualisation and formalisation. The following tests are elaborated on: recording and tracking agent behaviour, single-agent testing, breaking the agent, time-line sanity check, and multi-agent testing. The latter includes analysis on the variability of the model outputs with the settings of the proposed scenario.

Recording and Tracking Agent Behaviour

- By recording the inputs, states and outputs of agents and comparing them with what should happen following the flowcharts, is **confirmed** that the agent's states are changed and updated correctly.
- By creating a log of the input and outputs of each of the internal processes of the workers and comparing them with what should happen following the flowcharts is **confirmed** that the agents follow the correct decision pathway.

Single-Agent Testing With this method, you compare the inputs, internal processes and outputs of single agents and objects with a theoretical prediction. In this case this prediction is obtained from the flowcharts, that represent all actions and interactions that are happening in the system. For the actions that influence the agent's internal processes and outputs is checked whether these numbers correspond:

- **A single worker's perceptions and opportunities:** with an adequate level of status and power, low commitment level and high level of trust of others, and no friends with the union: the worker

¹<https://svn.eeni.tbm.tudelft.nl/IgorNikolic/education/students/FrederiqueDeGroen/thesis/model>

becomes friends with its company. The worker has the opportunity to apply for training or a job, and eventually applies for training every tick. His or her skills increase eventually to 1 (the maximum) and his or her status increases with 0.1 per year. → **confirmed**

- **The update of a single company:** with only one worker employed out of 10, it has a productivity of 10% → **confirmed**
- **The negotiation of a single union:** the negotiations continue until the resources of the jobs are bigger than the demands of the jobs; the workers stop striking when they experience more resources than demands. → **confirmed**
- **Strikes at a single company:** companies that experienced a single strike will always have strikes every year. Workers were continuously participating in strikes when they had certain characteristics, friends and status and power. This is resolved by changing that the workers do not strike anymore when they no longer experience job strain. → **solved**

Breaking the agent By setting all parameters and thresholds to the maximum, you try to break the agent or the system. This results in that all workers follow the same decision pathway; they all stop being a member of the union. → **confirmed**

Time-line sanity check The scenario is build for 41 ticks, or years; from 1999 to 2040. To check whether there are no emergent patterns or cyclical behaviour over a much longer time than the modelled time-space, the model is run with 200 ticks, or 200 years. As an example, see figure 5.4. Also for the rest of the outputs and indicators like average trust and number of strikes, it is confirmed that the outcomes stabilize within the expected time (41 years, 41 ticks). → **confirmed**

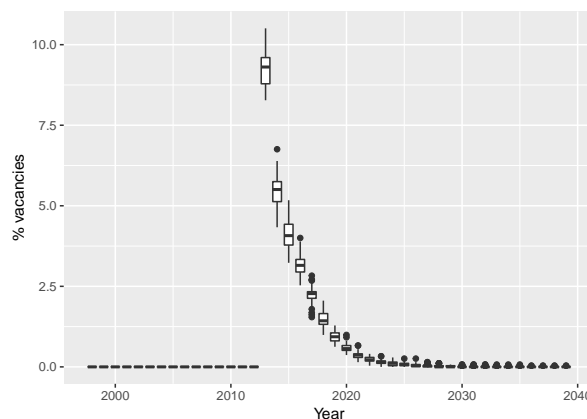


Figure 5.4: Timeline sanity - percentage vacancies

Multi-agent testing By testing the whole model it can become clear that some expected patterns are (not) there. A test with an insufficient number of workers proves that the productivity is indeed lower when there are not enough people to fill all the jobs. There were less than 300 workers for 400 jobs, and productivity dropped under the 90%.

Furthermore, the variability of outputs can be measured and evaluated when testing the full model. An example is shown in figure 5.5 to demonstrate that there are no big outliers, which is expected with the inputs of the tested model. Again, this also accounts for the following other output variables: the standard deviation for average status, average trust, average commitment and average skill level is between 0.01 and 0.08. The standard deviation for percentage vacancies, average productivity and job strain of the employed jobs is above 1. Again, this is expected, because of the sudden jump from 0 to 20 biorefineries (figure 5.4), the resulting decline in productivity, and the desired decrease in job strain.

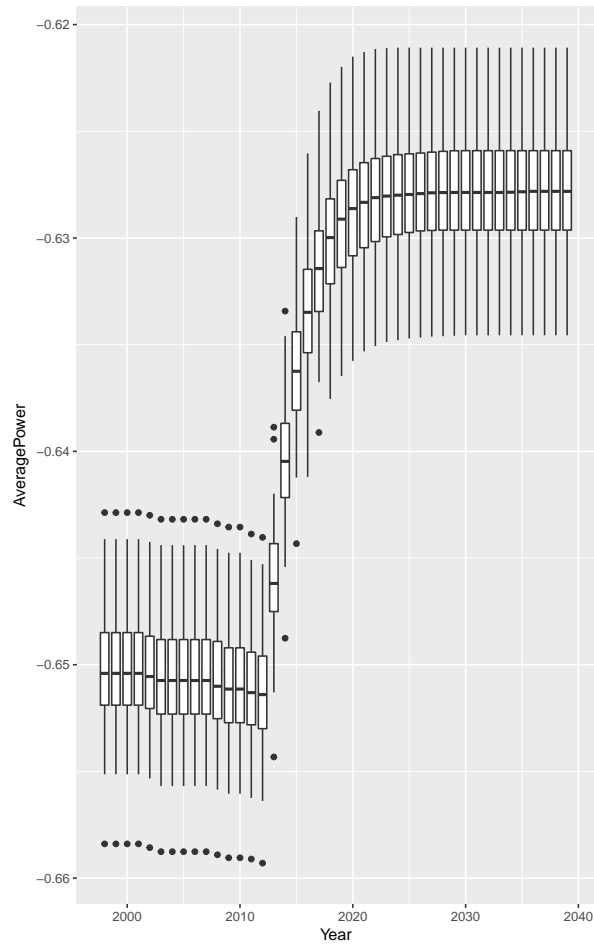


Figure 5.5: Variability testing - average power of the workers

While conducting experiments, a mistake was found in the code. The status and power were increased instead of decreased when workers were fired. This happened because of the wrong implementation of updating the worker's perceptions. When the workers supposedly decreased their perception of status and power below 0, which was the case for almost all workers, the status and power would be updated to 0. This means an increase in status and power for all of those workers. This is fixed by replacing the 0 with a -1; the workers cannot have a status and power lower than -1. This was the initial idea of the function to update the worker's perceptions but wrongly implemented. This has caused some delay, unfortunately, because all experiments had to be run again.

5.5. Sub-conclusion

The second research sub-question can be answered with the current and the two former chapters: *What is a possible method to simulate the effects of an industrial symbiosis network on the local workforce, and vice versa?*

Agent-based modelling is chosen as the tool to simulate the effects of an ISN on its local workforce and vice versa. The ABM made for this thesis attempts to represent the people under subject, the sugar industry workforce of Norte Fluminense, as social human beings. These workers live in a world which is - in their 'mind' - made out of perceptions of power, status, frames of reference and fields of opportunities. Furthermore, the human side of the workers is represented by their attributes, or character traits; all workers have a certain level of commitment and trust. The actions and interactions of the workers with the union and the companies are all determined by their perceived level of power, status, commitment, trust, and fields of opportunities.

The companies in the model are much more simplified than the workers. Their decisions are solely based on their aim to fill all their vacant jobs with current sugar industry workers, of which the success of filling these jobs depends on the worker's applications. Since the companies are in a system with only the local current sugar industry workforce, the decision for hiring only locals is already made for them. The choice that is made to not include non-local workers arose from Santos and Magrini (2018) their proposal to sustainably develop the region, which is assumed to also include the workforce in that region.

As the companies, the union is also more abstractly represented than the workers. They act on their aim to improve the working conditions for the sugar industry by negotiating with the companies about a decrease in demands and increase of resources. The union negotiates with the companies when the number of complaints from the workers has reached a certain threshold; the achievements of the negotiations depend on whether and how many strikes the companies have experienced.

Agent-based modelling, especially for this kind of proof-of-concept model, implies that the effects of the agro-ISN on the workers and vice versa will be measured with emerging patterns. These can include all the states of the agents: the worker's trust, commitment, power, status, skills, and job strain; the companies vacancies, productivity, strikes, and the union's negotiations, number of complaints received, and requalification trainings given.

Overall, this thesis presents a possible method to simulate the effects of an industrial symbiosis network on the local workforce and vice versa. However, it is noted that this is only one of the many ways to interpret and conceptualise the real-world system under study.

6

Exploration and experimentation

The seventh step of the agent-based modelling process is described in this chapter, which starts with a paragraph explaining the initial set-up of the experiments. Thereafter, in section 6.1, the aim of the exploration and experimentation is made clear, as well as the input parameters and the relevant output variables. Furthermore, the time frame, scenarios and scenario space that are explored are elaborated on. In section 6.2 is explained how exactly those scenarios and scenario spaces are explored. The experiment designs is discussed in section 6.3. A short explanation of the data analysis is given in section 6.4, of which the resulting emergent patterns are elaborated on in chapter 7.

Initial set-up This thesis' social model is constructed with expectations of an external input of the number of companies per year, which type of companies and how many jobs are available per company. To be independent of Santos, these inputs are simulated in the model. Therefore, from 1999 to 2013, the number of farms and mills is equal to that of Santos' model. From the start of the model, 1999, it is assumed that then other industries already exist.

Initially, companies going in and out of operation or going bankrupt and being founded was simulated very static. Only in 2013, there were 20 biorefineries founded. Furthermore, there was the option of forcing a random company to go bankrupt every year which consequently led to them firing all their employees. This resulted in a modelling artefact: these companies only went "bankrupt" for one year and started operating again the next year, in which they hired again the needed workers.

After exploring this set-up, it became clear that the artefact and static in- and out-going of operation of the companies did not simulate the expected dynamics from Santos' model and her thoughts of the expected future. Thus, a new company dynamic was brought into experimentation. The years from 1999 to 2013 are the same concerning the initial set-up. However, from 2013, a dynamic is created to simulate semi-randomly the bankruptcy of farms, biorefineries and other industries, and the foundation of biorefineries and other industries. The semi-random formalisation (appendix B, assumption 24) for this company dynamic can be found in appendix G. The mills do not go bankrupt because without those there would not be any feedstock for the agro-ISM. The general trend of the company dynamics can be seen in figure 6.1, of which the number of farms is divided by ten to show more clearly the change in the number of mills, other industries and biorefineries. Figure 6.2 depicts the number of farms, mills, other industries and biorefineries over time in a single run, as an example.

The number of jobs per farm and mill is equal to those of Santos and Magrini (2018), the number of jobs per other industry and biorefinery is guestimated: respectively 10 and 20 per company. This number is not based on real data because the model is made as such to receive the number and types of companies and number of jobs per company as input. This will be the case when the model is combined with, for example, Santos' technical model. The sources for the historical data on the number of mills and farms can be found in appendix F.

This chapter includes elaboration on the experiments that are done with the two scenarios as discussed above: the initial, static company scenario and the second, dynamic company scenario.

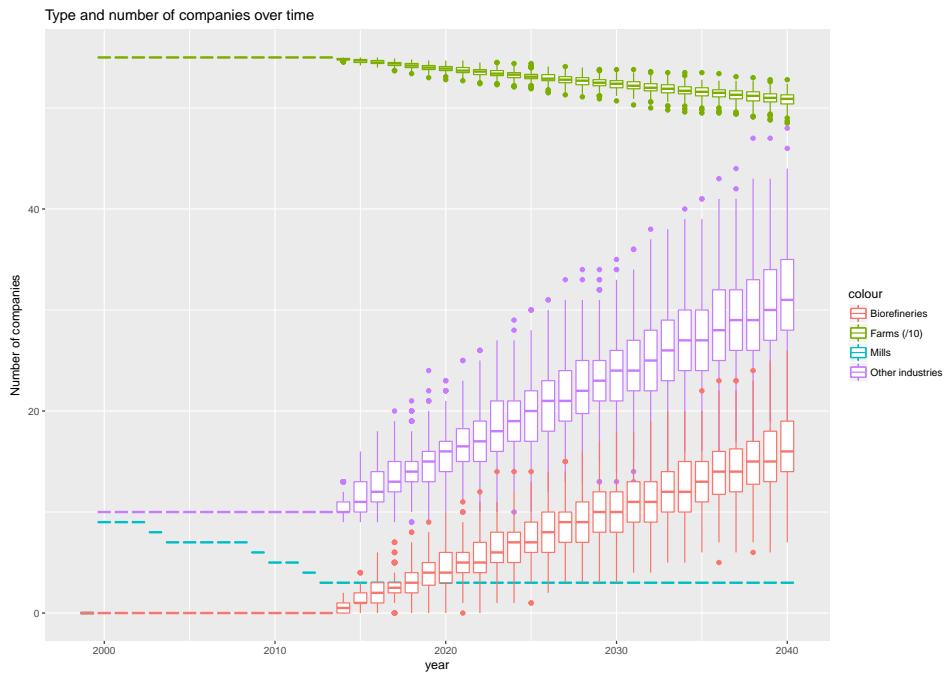


Figure 6.1: The number and type of companies over time in the more dynamic company scenario, 900 runs.

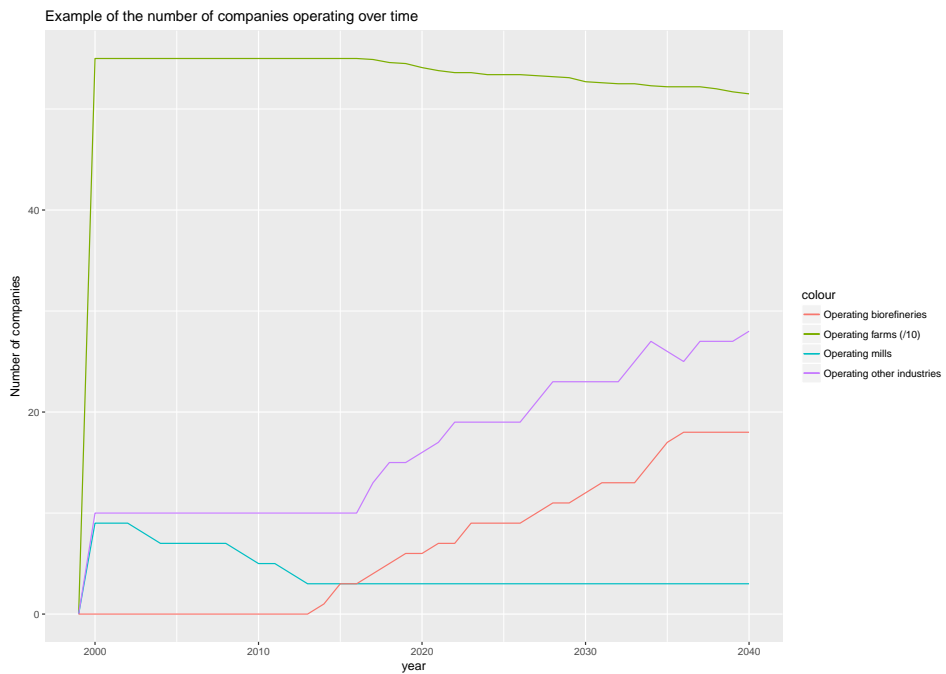


Figure 6.2: An example of a run with random company dynamics.

6.1. Aim of the exploration and experimentation

The aim of exploring this model is to run experiments that produce data that is useful for gaining insights into the model and research questions. Especially, how the Norte Fluminense sugar industry workforce is affected by and affects the proposed agro-ISM in terms of (lack of) employment, job quality and skill level. To investigate these variables, the outputs of interest are:

- **Percentage vacancies** of the companies; i.e. jobs for which the company cannot hire anyone.
- **Percentage unemployment**; the part of the workers that do not have a job.
- **Percentage job strain of employed jobs**; the part of the total number of employed workers who experience job strain, i.e. when the job requires more demands than the resources it offers.
- **Average skill level**; the average level of the skills of the workers.
- **Average power**; the average perception of the workers' own power.
- **Average status**; the average perception of the workers' own status.

Additional outputs of interest for further research, but for now outside the scope of this thesis, could be: the percentage job strain of the total jobs, i.e. the part of the all the jobs in the system for which the workers would experience job strain; the percentage secure workers, i.e. the part of the workers that feel they have adequate power, which results in feeling secure; and the percentage satisfied workers, i.e. the part of the workers that feel they have adequate status, which results in feeling satisfied. Furthermore, the model allows for a large set of thresholds and parameters to have different values. The input variables that is experimented with, and the range in which the experiments are performed, are:

- The **number of workers** in the model, with a 100% being the initial number of jobs available in 1999: 0 - 200%.
- The percentage workers that is initially a **union member**: standard set at 37%.
- Height of the **requalification subsidies**: 0 - 100%.
- Height of the **hiring subsidies**: 0 - 100 %.
- **Subsidy options**: both always on or off with different levels of subsidies, 4 years on / 4 years of for both subsidies in phase, 4 years on / 4 years of for both subsidies out of phase, exponential increase of both subsidies, exponential decrease of both subsidies, randomly distributed subsidies over 20% of the time, random height of the subsidies every year.
- All workers have an **initial power and status deficit**: standard true.
- **Thresholds**:
 - Power of the workers is insufficient at: -1 - 1.
 - Status of the workers is insufficient at: -1 - 1.
 - Workers characteristics (both) are high at: 0 - 1.
 - Workers characteristics (both) are low at: 0 - 1.
- **Level of in- or decrease** of the workers states:
 - Maximum in- or decrease of commitment per year: 0 - 1.
 - Maximum in- or decrease of trust of others, per year: 0 - 1.
 - Maximum increase of status for skill increase per year: 0 - 1.
 - Maximum increase of status for having a better job quality than the year before: 0 - 1.
 - Maximum decrease of status for having a worse job quality than the year before: 0 - 1.

The experiments are conducted under specific conditions which are defined by the time frame, different scenarios and scenario space (van Dam et al., 2013). These are explained in the following paragraphs.

Time frame In the verification step (section 5.4), a time-line sanity check has been performed with positive results: the time that is set for the model (41 years) is enough for the formation of the desired emergent pattern. Furthermore, a longer timeline would result in the workers not being able to work anymore because of, for example, old age or death of the workers. The new dimension that this expanded time frame would add, for example, children being born and starting to work in the sugar industry, falls outside the scope of this thesis. Therefore, the time frame used for all of the experiments is from 1999 to 2040.

Scenarios As distinguished by van Dam et al. (2013), there is a difference between scenarios and scenario space in the exploration of a model. They link hypotheses of type one to scenarios and hypotheses of type two to the scenario space. The first type of hypothesis should provide insights in the emergent pattern of interest (section 4.1), to repeat: *workers are able to switch to a "better" job, defined by skill level and job quality*. Furthermore, it is expected that the overall job quality of the employed jobs improves, the agro-ISO is able to fill their jobs with locals and the worker's perception of their own status and power increases. Considering this is a proof-of-concept model, there is no "right" answer; there are no hypotheses that can be confirmed or rejected. Furthermore, this emergent pattern of interest is not a real-world observed regularity, and thus cannot be falsified with real-world parameter values, since this data is not available. On the other hand, we are able to create a scenario that is thought to be most similar to the current situation, and what might be simulating the future behaviour of the proposed situation over time.

After an iteration of experiments, the parameters for these more realistic current and proposed scenarios are determined (see appendix G), and are further on respectively called the *current scenario* and the *proposed scenario*. These scenarios are explored by experiments discussed in section 6.2 and 6.3. The differences between the current and proposed scenario, and additional options for the scenarios are:

- **Biorefineries:** In the current scenario there are no biorefineries, in the proposed scenario with static company simulation there are 20 biorefineries introduced in 2013, and in the proposed scenario with dynamic company simulation a semi-random number of other industries and biorefineries are introduced and a semi-random number of farms, other industries and biorefineries go bankrupt.
- **Bankruptcy:** In addition to both scenarios with static company simulation, there is the option of making a random company go bankrupt every year as a simulation of market forces.
- **Subsidies:** The subsidies that are supplied every year differ: in the current scenario there are none, in the proposed there are 25% requalification and hiring subsidies supplied annually. This represents respectively the amount of money necessary to requalify 25% of the workers that are at that moment working in farms or mills, and the amount of money necessary for each company to hire 10% less qualified workers for 25% of their total number of jobs. These subsidies are not supplied in the current scenario because they are specifically implemented for requalifying and hiring the current sugar industry employees.

Scenario space Explorations of the scenario space aim for investigation of conditions under which the emergent pattern of interest might occur, and whether there are parameters that influence that pattern and how (van Dam et al., 2013).

The focus lies on the relation of certain parameters and the resulting behaviour. This type of exploration asks for large experiments with for example broad parameter sweeps, which are explained in section 6.3. *All the explorations of the scenario space are designed within the proposed scenario, which means every experiment is configured as the static company scenario or the dynamic company scenario, and certain levels of subsidies supplied over time.*

6.2. Explorations

Since there are many levels of uncertainty in the model - no data or examples of similar ABMs using the same theories - no hypotheses are used, but solely explorations of the scenarios and scenario space. The explorations that are used for experimentation are the following:

Exploration of the scenarios over time

1. The two current standard scenarios: with and without a random company going bankrupt.
2. The three proposed standard scenarios: with and without a random company going bankrupt, and in addition the more dynamic company scenario.
3. The emergent pattern of interest is expected to appear in the proposed scenarios, and all scenarios are investigated with regards to the outputs of interest (section 6.1).

Exploration of the scenario space

1. Exploration on the scarcity and abundance of workers in terms of their unemployment, and the company's vacancies and average productivity. The percentage workers are measured on the initial number of jobs in 1999, with that number of jobs equal to a 100% workers.
2. Exploration how different sets of subsidies (section 6.1) influence the outputs of interest.
3. Exploration how different levels of threshold and levels of changes in parameters influence the outputs of interest.

6.3. Experimentation design

Experiments are designed in a way to explore the scenarios and the scenario space, as discussed in section 6.1 and 6.2. An overview of all the experiments performed can be found in appendix G. The number of repetitions of every run is restricted by the large number of parameters that can be experimented with, the large number of outcome variables and the many different experiments that can be done due to the exploratory nature of this research. For example, a full factorial experiment with all of the thresholds would take the authors personal computer around 3 full days to run (70 hours); this would be too time-consuming because it would be only one of the many experiments that need to be done.

Latin Hypercube Sampling (LHS) is a statistical method to generate evenly distributed sample points for variable inputs, with a maximum number of runs (McKay et al., 1979). It is however chosen that the experiments are only run with one set of input variables or that the experiments are (partly) full factorial. An exploration through different values of input variables, thresholds and maximum in- or decrease of the worker's states have pointed out the differences are not substantial enough to generate LHS input variables.

Starting with the scenarios, an exploration is done on the dynamics over time for different settings in the current and proposed scenarios. The scenario space is investigated with a few different experiments. The exploration of the scarcity or abundance of workers is investigated through experiments for 0 to 200% abundant workers. Subsidy height and options are explored through various experiments from 0 to 100% for both subsidies; initial experiments look at a broad range (from 0 to 100%), while a further investigation looks at smaller steps (from 0 to 25% and from 0 to 10%). The characteristics and power and status thresholds and increments are explored with 4 different configurations, these can be seen in appendix G in table G.2.

6.4. Experimentation outcomes - data analysis

The data¹ from the experiments is analysed and visualised with R² (R Core Team, 2013). Through an iterative process of data exploration, identifying emergent patterns, and again performing experiments, the patterns of interest are found in order to answer the model questions, and eventually also the research questions posed in chapter 1. These patterns are shown, interpreted and explained in chapter 7. As van Dam et al. (2013) put it, results of the experiments can explain "[...] whether the regularity is stable or not, whether there are any concurrent behaviours of interest, or what might be the future behaviour of the whole system under investigation".

¹<https://svn.eeni.tbm.tudelft.nl/IgorNikolic/education/students/FrederiqueDeGroen/thesis/model/Experiments/Data>

²<https://svn.eeni.tbm.tudelft.nl/IgorNikolic/education/students/FrederiqueDeGroen/thesis/model/Experiments/R-scripts>

7

Results

First, the most relevant outcomes of the experiments from the last chapter are described in section 7.1; it elaborates on the observed emergent patterns found from the explorations of the scenarios and the scenario space. Second, section 7.2 discusses the use of the model for the studied case. The third and final section of this chapter concludes with answering the final model sub-question, the main model question and the final research sub-question.

7.1. Emergent patterns

By analysing the data from the experiments it can be determined if the expected or desired regularity emerges and when. Different types of emergent patterns of interest include **dynamic behaviour**, e.g. exponential over time or over a certain variable; **metastable behaviour**, outcomes of multiple runs that for example cluster in two sets; **attractor changes**, a sudden change or collapse in the experiment outcomes; and when there is a **lack of a pattern**, random outcomes that do not seem to follow any pattern (van Dam et al., 2013).

To explore the different scenarios as explained in chapter 6, the dynamics over time of all output and internal variables are analysed. This enabled further exploration of interesting patterns through experimentation with the shortage or abundance of workers, value and timing of subsidies, and thresholds and increments. In the following sections, the emergent patterns of interest are elaborated on.

Behaviour of the outcomes of interest in the current and proposed scenarios

The behaviour and interesting patterns that are found in the exploration of the current and proposed scenarios are described in the following paragraphs. Figure 7.1 consists of six graphs, each with an output of interest on the y-axis, over the time on the x-axis; from 1999 to 2040. The different scenarios are indicated with colours, of which the legend names are linked to the names of the scenarios in chapter 6.

Dynamic behaviour First, the dynamic behaviour is described per outcome of interest as described in chapter 6. These will help to answer the main model question. The outcomes in figure 7.1 are explained from left to right and from top to bottom:

- The average power of the workers increases with the emergence of the agro-ISN, because there are more companies where the workers can be hired.
- The average status of the workers is increased by the decrease in job strain in 2007 and 2016; it is even more increased by the average skill increase of the workers, which in turn is caused by the availability of requalification training.
- The skills of the workers are increased because of the requalification training organised by the union.

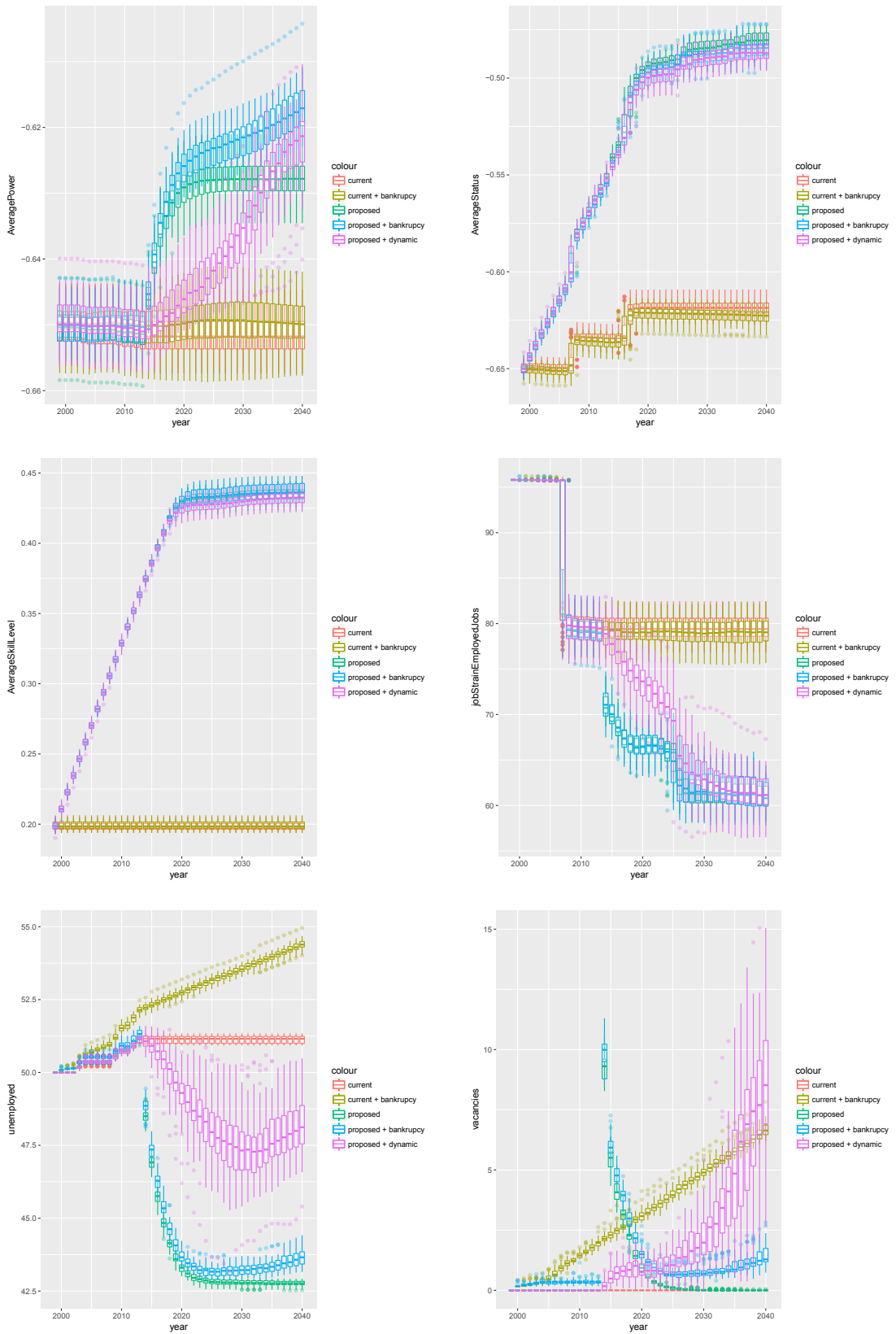


Figure 7.1: The six outcomes of interest over time with five different scenarios.

- Job strain is decreased because the 50% threshold of complaints is reached in 2007, and again in 2014. The amount with which the job strain decreases is dependent on the number of strikes per company. More strikes, especially more companies with strikes, means a lower percentage overall job strain after negotiation.
- Compared to the static scenario, where only 20 biorefineries are founded in 2013, a more dynamic in- and out-going of operation of the companies result in a larger variability in the unemployment and vacancies percentages.
- Unemployment causes a reduction in power; the years where unemployment rises slightly until 2013, caused by the decline in the number of mills, are the same years as for where the average power decreases slightly.
- Vacancies are largely influenced by the skill increase of the workers and the in- and out-going of operation of companies: with only a small increase in average skills, the percentage of vacancies rise quickly over time.

Emergent pattern of interest The emergent pattern of interest is found in the proposed scenarios: workers are able to switch to a "better" job, defined by skill level and job quality. The average skill level of the workers rises with 118% and there are around 30% fewer workers that experience job strain in 2040. This is achieved with workers completing an average of 11,621 requalification trainings from 2000 to 2040; which is calculated by taking the average of the 150 experimental runs that have been performed with all the proposed scenarios (appendix H). Further expectations about increasing overall job quality and the increase of power and status of the workers are all met in the three researched proposed scenarios. The incidence of job strain over all of the jobs decreases with approximately 28% (appendix H); the power and status of the workers increase with respectively 0.028 and 0.166 (top two graphs in figure 7.1). The agro-ISBN is able to fill their jobs with the local sugar industry workers, but if the industry keeps growing over time, there are not enough workers from the current sugar industry with the ambition to acquire sufficient skills to work in the new companies.

For all scenarios, the number of complaints has built up to 50% in 2007, that is also when there is a big drop in incidence of job strain. That same year saw a total average of 689 strikes in 95 companies over all scenarios. This counts up to an average of 7 strikes per company over 8 years.

The main outcome of the scenario exploration is that the company dynamics, i.e. the rate at which companies are founded and go bankrupt in the system, is very important for the model results. It mainly influences the rate at which workers must be (re)qualified for the newly created jobs.

Distrust with an abundance of workers

With a workers abundance, the trust decreases strongly as can be seen in figure 7.2. This relatively high trust with a workers shortage and relatively low trust with a workers abundance can be explained by the job shortage. Workers' trust decreases from the experience of applying for jobs and not being hired. Since the number of jobs is the same for every percentage of workers, it is predefined that there will be a job shortage. However, over time, new biorefineries and other industries are founded after which trust levels increase again to a relatively stable position (appendix I).

Trust in employment Considering the found pattern of distrust with an abundance of workers in the real world, it can be assumed that there is always an abundance of workers, or job shortage. There are no countries, or even regions, where there is no unemployment or vacant jobs (OECD, 2017b; Organization, 2018). Results of a study on the psychosocial work conditions, unemployment and trust of the population in a Swedish region pointed out that 40% of the men and women in the working population had "low generalized trust in other people" (Lindström, 2009). The odds of low trust levels of people included in the job strain and unemployed groups were significantly higher than those in the relaxed group. The latter is considered the most beneficial in terms of health. Comparable to the indicator of job strain used in this thesis, Lindström (2009) uses the term job strain if one has little control over their work situation in terms of freedom, creativity, repetitiveness, and responsibility, and the demands of the worker in terms of skills required, work pace, intensity, and the possibility to keep up with colleagues, is high.

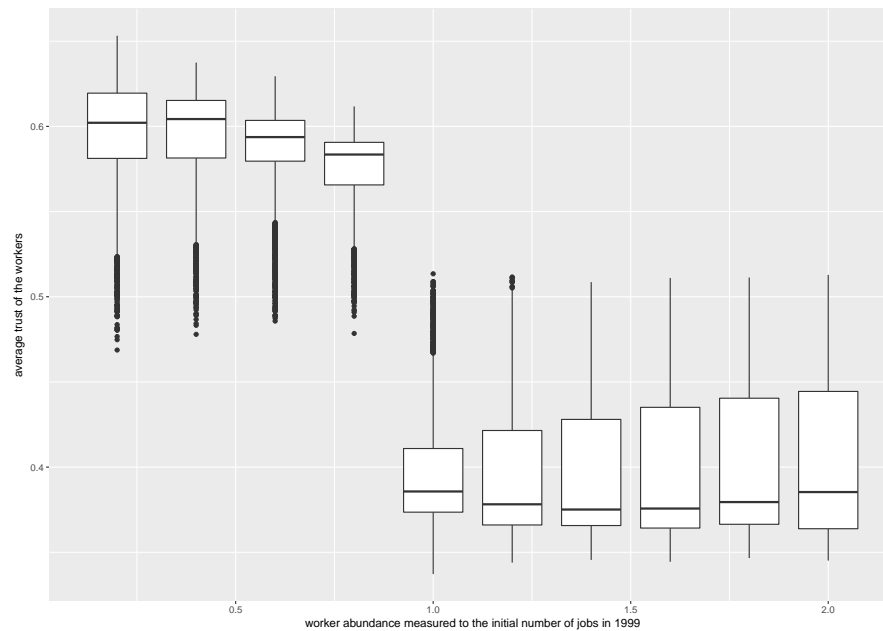


Figure 7.2: Average trust of the workers with different percentage initial workers measured to the number of jobs in 1999. There is a strong downhill negative linear relationship, Pearson's correlation coefficient $r = -0.79$.

Hiring subsidies not effective when not aimed at specific groups

The exploration on how different sets of subsidies influence the outputs of interest as described in chapter 6, resulted in the following findings. Hiring subsidies seem to be ineffective concerning the average skills, power, status, unemployment and incidence of job strain of the workers, and vacancies of the companies - especially compared to the requalification subsidies. Appendix J contains graphs with a comparison of 0 and 100 hiring subsidies, with no significant difference between the two concerning the aforementioned outputs. Figure 7.3 is an example of a comparison between the least and most hiring subsidies (upper x-axis), for the percentage vacancies (left y-axis), over time (lower x-axis).

Hiring subsidies are aimed at providing jobs for the (low-skilled) unemployed, certain minority groups, or for companies to be able to fill vacancies where, for example, the requalification subsidies have created a labour market for. However, as a result of the formalisation of the hiring subsidies, the hiring subsidies in the model are not specifically aimed at, for example, the lower skilled workers. In the model, hiring subsidies are aimed at the sugar industry workforce in general, since they are the target group for achieving sufficient employment in the agro-ISN. Furthermore, workers with a higher skill level than required for the job can also be hired with hiring subsidies.

Almost no workers who need the hiring subsidies are hired with hiring subsidies. This is analysed by only counting the workers that are hired with a skill level below the required skill level of a certain job, measured over 50 repetitions of an experiment with hiring subsidies set at a 100. From the workers that apply for jobs and are hired without needing the hiring subsidies, 25% is hired over the full 41 years. The highest level of hiring subsidies (100) means that companies are able to hire every worker they need with hiring subsidies. Since the companies first hire with these subsidies, in this experiment they only hire with hiring subsidies.

A more in-depth investigation into the model - also with lower hiring subsidies - shows that indeed not all workers that are hired with hiring subsidies needed those subsidies; they already had enough skills for the job. For example, in 2013, the three workers that are all hired with hiring subsidies in a new biorefinery, all had a skill level higher than 0.9, while the skill level required for a biorefinery job is 0.6. This emergent pattern can be interpreted as a mismatch between the worker's occupational ambitions and the companies that have no specific aim for the hiring subsidies.

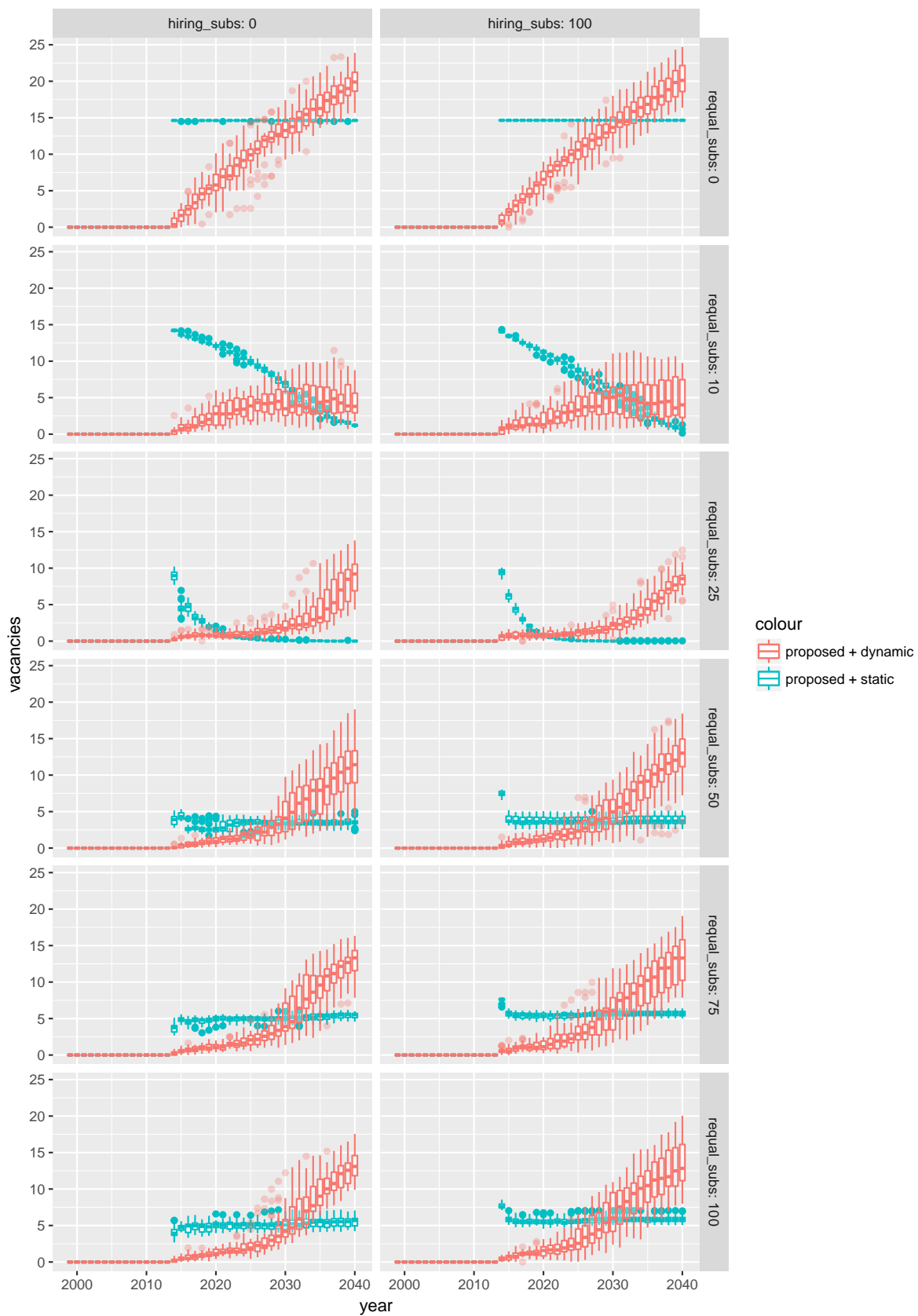


Figure 7.3: The percentage vacancies over time, compared to the proposed static company and dynamic company scenario, with different combinations of the value of the hiring and requalification subsidies, that are supplied annually. The number of workers is double the initial number of jobs.

Slow division of requalification subsidies result in low unemployment and low vacancies

More subsidies do not always generate better results, as with the hiring subsidies. A slow division of the requalification subsidies, i.e. subsidies of a low value supplemented continuously over time, is beneficial for keeping the percentage vacancies and unemployment low (appendix J). Additionally, the average power rises higher than in a scenario where more subsidies are supplied (appendix J). In order to keep the percentage vacancies and unemployed workers as low as possible, ten requalification subsidies should be supplied which corresponds with a number of trainings that equals 10% of the total farm and mill jobs. In 1999, this is equal to 228 requalification trainings; this is almost the same in 2012 (223), the last year where the number of farms and mills are the same in every experiment.

This pattern emerges because in a scenario with 10 requalification subsidies, the companies have sufficient time to find the appropriate workers for their jobs, and not all of the workers have to be divided into their newly created jobs at once. This causes mismatches for workers with different levels of skills and jobs requiring different skill levels. As noted in chapter 1, most countries face issues with skill mismatches. This mismatching goes both ways: the companies are not able to find adequately skilled workers for their jobs, while the qualified unemployed have a hard time finding the appropriate job that matches their skills (OECD, 2017a).

Regarding the timing of the subsidies, the 4 years on and off option could be beneficial for very long-term planning, because, for example, the average skill level keeps on increasing, and still has an upward motion in 2040. Similar to the slow supplementation of subsidies is that same timing option - 4 years on and off - preferable considering the vacancies and unemployment (appendix J). However, the results of all of the different subsidy options that are not continuously supplied with the same value, are less beneficial than those that are always continuously supplied with the same value.

In a news article from January 2018, it is announced that industry unions in North and Northwest Fluminense, in collaboration with SENAI, offer 326 free (re)qualification courses aimed at industrial workers, their dependents, the unemployed who have already worked in the industry and the general public (de Itálva, 2018). In addition, there are more than 8,000 course openings on the planning for April 2018. SENAI, the National Service of Industrial Training in Brazil, is a non-profit organisation that is said to be renowned for its professional education, especially in technological services for the Brazilian industry (da Industria, nd). Their objective is to prepare and improve skills of the workers to meet the labour market demands. At the qualification courses, new skills can be developed, similar to the requalification training in the model. In Norte Fluminense, vacancies for the training are offered by over 10 unions, including SISERJ, the union representing the sugar industry in Rio de Janeiro (de Itálva, 2018).

The workers skills range increases

From 1999 to 2040, the workers have an overall large skill range. In figure 7.4, the average skills of employees per company are plotted for 2000, 2010, 2020, 2030, and 2041. With 10 requalification subsidies, the average skill level rises, but the variation of the worker's skills also increase, from a standard deviation of 0.11 in 2000 to 0.20 in 2041.

Delayed negotiations of the union results in a lower overall job strain

Experimentation with the characteristics thresholds has resulted in finding another emergent pattern. More extreme high (0.9) and low (0.1) characteristics thresholds, instead of respectively 0.3 and 0.7, can be seen as a situation where there are a lot of people with the same kind of character traits. There is a larger group of people with a mild character in terms of commitment and trust. These mildly characterised workers complain less, but they are still participating in a lot of strikes. Because it takes a much longer time to reach the 50% threshold for the union to start their negotiations, the greater part of the companies has already experienced a number of strikes. Therefore, the job strain drops to the lowest level found in all of the experiments (figure 7.5). However, it takes 26 years to drop instead of 8 years.

Higher power for stubborn workers

People that are not so quickly influenced by others concerning their trust - stubborn people in this sense - increase their power more than people that react more strongly to others in the case of trust

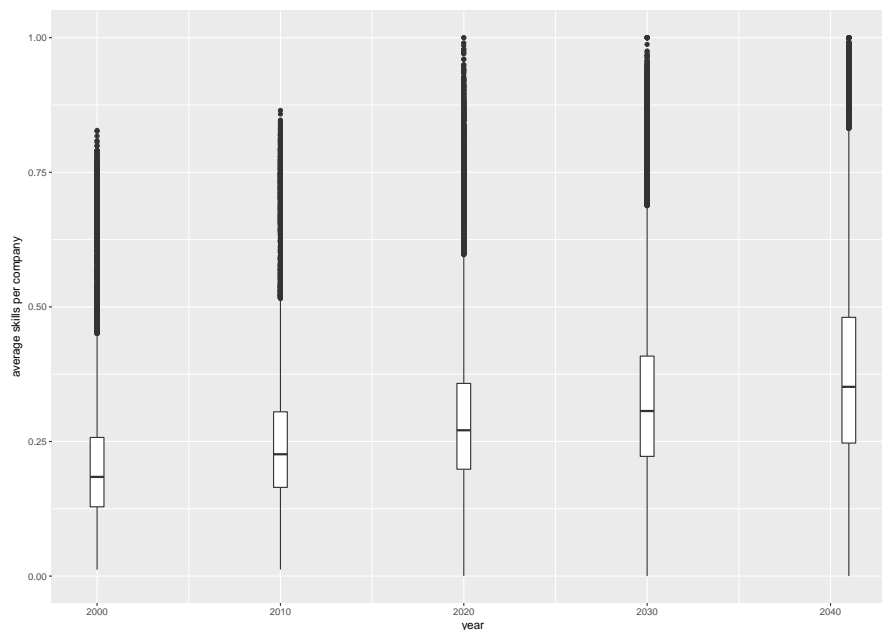


Figure 7.4: Average skill level of the workers employed per company, over time.

(appendix L). The differences between the average power of workers with a trust in- or decrease of 0.05 and workers with a trust increase of 0.2 for being respectively hired or not hired when applying for a job, are significant (Pearson's Chi-squared test, p-value = 0.017).

Highly committed workers result in low unemployment and vacancies

The lowest unemployment and lowest vacancies levels are measured with the lowest trust in- or decrease (0.05) and highest commitment in- or decrease (0.2) (appendix L). The difference between this increment parametrisation and the standard settings of 0.1 in- and decrease for both trust and commitment, is however not significant. Pearson's Chi-squared test gives a p-value of 0.29 and 0.12 for respectively the differences in unemployment and vacancies between the scenarios.

Anyhow, with a higher commitment - average commitment is highest in the mentioned case (appendix L) - more people will stay at their current job. This high commitment is caused by the high increment level and increases in job quality, although the latter is not specifically lower than in other cases.

Low ambition of quickly satisfied workers

A lower status increase (0.05) for new skills gained, results in a higher average skill level of the workers (appendix M). When the increase is high (0.2), the workers do not feel the need to obtain more skills after a short period of training time. This quicker satisfaction of the workers affects the vacancies, unemployment, and job strain negatively (appendix M).

7.2. Model use

As noted in the introduction, an example of the use of this model is to merge it with Santos' model. Both models would benefit from this combination because it provides another layer of depth. Whereas one model would primarily be aimed at the individual and the other mainly at the institutional level, the combination of these two models makes it possible to have both. The models are merged, however, no experiments were designed or performed with the merged model because of a lack of time. Therefore, the use of the model is demonstrated as a stand-alone model for the relevant actors in the studied case.

Advise for the policymakers of the agro-ISN The questions posed in chapter 4 related to the targeted policymakers can be answered with the model results. The policymakers responsible for the

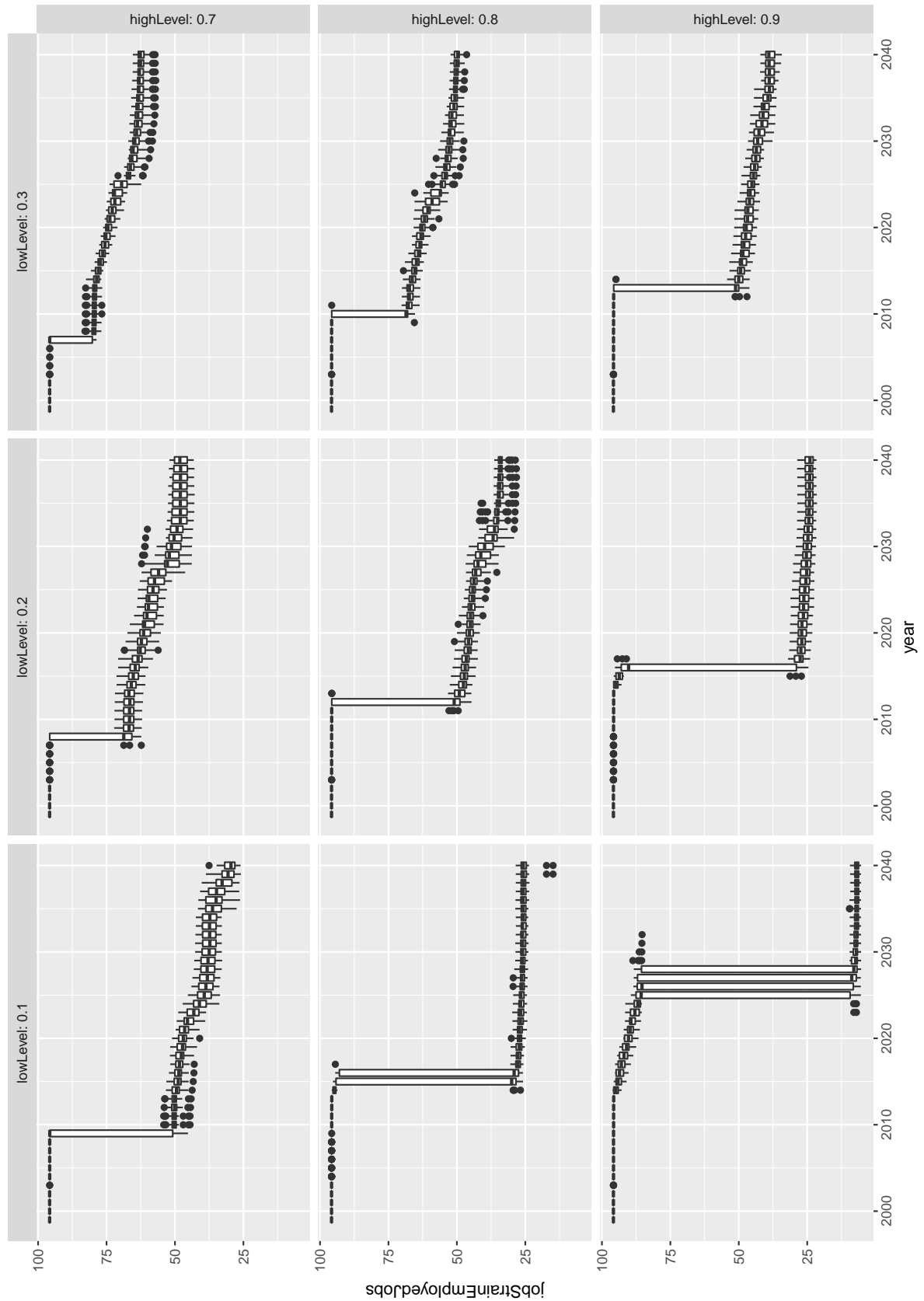


Figure 7.5: The percentage job strain of the employed workers with different characteristic threshold levels in the proposed dynamic company scenario. In the top x-axis, three options for the low level of both the characteristics are used as input. In the right y-axis, three options for the high level of both the characteristics are used as input. The boxplots in the graphs represent the percentage of job strain over all employed jobs measured over the left y-axis, over the years shown in the bottom x-axis.

proposed agro-ISN could ask themselves *whether they should promote the agro-ISN with requalification and hiring subsidies, and if so, how do the social interactions between the workers, union and companies and worker characteristics influence the foreseen outcomes?*

With the insights gained from the model, it is advised to those who decide over the policies for subsidies in the proposed agro-ISN to invest with moderated requalification subsidies over the long-term. This enables the requalified workers and newly created jobs to be matched more correctly. With regards to the size of the requalification subsidies, in the scenario with ten requalification subsidies when provided annually, from 2018 to 2040 an average of 4886 requalification trainings are received. To give an indication of the financial costs for these trainings, a comparison is done with the RenovAcção project. Investments by the Inter-American Development Bank (IDB), UNICA and partners added up to R\$2,403,494 and in the first phase, 2,000 vacancies for retraining were offered (UNICA, 2010). The sources of information concerning RenovAcção are unclear whether these investments were only used for these 2,000 trainings, or if they were used for more, or if more investments have been made. In the situation where the R\$2,403,494 was solely used for the 2,000 trainings, R\$1,202 is spent per training (UNICA, 2010). For a total of 4886 trainings, this would add up to an investment of R\$5,871,736 over 22 years for the studied case. It is assumed that the investment made by the IDB, UNICA, and partners in the RenovAcção project was specifically aimed at that first year where they offered 2,000 course vacancies.

Hiring subsidies could be implemented, instead of long-term, with limited time. Orszag and Snower (2003) analysed that if workers have the chance of a wage increase with the increase of their experience, short-term hiring subsidies provide better results than long-term subsidies to compensate, for example, a low wage. The subsidies must, however, be aimed at a specific group for a specific target. For example, Kitao et al. (2011) show that hiring subsidies have a positive effect on job creation when aimed at low-skilled workers and this effect is even larger during a recession, which can be compared to the decline of an industry like the sugar industry in Norte Fluminense. When applied correctly, hiring vouchers, for example, can improve welfare and employment, are self-financing and do not raise earnings inequality (Brown et al., 2011). However, this is information found in literature. From the model results, the only conclusion that can be made is that hiring subsidies must be aimed at a very specific group of people. For the policymakers is advised to use specifically aimed hiring subsidies - when needed - as short bursts to push the labour market if the development of the region is not going as expected.

7.3. Sub-conclusion

The final model sub-question, main model question and final research sub-question can be answered as a conclusion of this chapter. First, the final model sub-question is answered: *How do the subsidy choices and modelled decision behaviour influence the effects of an agro-industrial symbiosis network on the current sugar industry workforce, and vice versa?*

The influence of the subsidy choices and modelled decision behaviour is analysed from three perspectives: the availability of workers (shortage or abundance), the value of supplied subsidies and their timing, and the modelled decision behaviour in terms of the characteristics and power and status thresholds and increments.

The effects of the agro-ISN on the sugar industry workforce and vice versa are indeed influenced by the subsidy choices and modelled decision behaviour; how these influence the bi-directional effects is explained on the basis of the identified emergent patterns.

The trust of the workers declines when there are not enough jobs available for everyone that desires to change jobs, and rises again if more jobs are available. The agro-ISN can therefore influence the workers in terms of increasing their trust with the advent of more companies and thus more jobs. Workers with a higher trust of others are more inclined to apply for a new job or job training, which could lead to a better job with perhaps a higher job quality and more skills required for the workers, and for the agro-ISN sufficient applicants for their vacancies.

Hiring subsidies can theoretically be effective, but in the way that they are formalised this is not the case. Therefore, a change in the value or timing of the hiring subsidies does, almost entirely, not influence the interaction between an agro-ISN and its workforce. Hiring subsidies should be more specifically aimed at certain people, for example, the low-skilled workers.

Requalifying the workers - potentially with subsidies - is essential for the successful realisation of an agro-ISN if the current workforce of the sugar industry is considered as the preferred employees. Without requalification training, there would not be enough adequately skilled people in the region to fill the vacancies of the new companies in the agro-ISN. A slow division of the supply of requalification trainings is preferred over a big burst of trainings; time is needed to match the (acquired) skills of the workers with the vacancies of the newly found companies. A continuous supply of requalification trainings provides the best results concerning the power, status, skills, job strain and unemployment of the workers, and vacancies of the companies. However, this might not be representative for a real-world scenario. A more realistic scenario for requalification training is that subsidies are supplied every other four years; this scenario gives the best result from the different scenarios created. The subsidy options that are explored for both subsidies are four years on and off in or out of phase, exponential in- or decrease, completely random and only sometimes available. To conclude, requalification subsidies greatly and positively influence the effects of an agro-ISN on its workers and vice versa.

Even with the average skill level increasing, there is a wide range of skills amongst the workers. This can imply that there should be a sufficient range of skills necessary within the jobs created by the agro-ISN so that all workers are able to find a job appropriate to their ambition and skills. The wide range of skills is caused by the modelled decision behaviour of the workers, which makes it possible for each individual unique agent to follow their own pathway. With this identified pattern is shown that indeed not all agents have the desire to obtain new skills through requalification training.

A pattern that was discovered concerning the modelled decision behaviour, is that delayed negotiations of the union can result in larger achievements with regards to lowering the incidence of job strain. This is the case for a larger group of workers with a mild character in terms of commitment and trust. The influence of the workers on the agro-ISN's quality of the jobs is much greater with this configuration than when the characteristic thresholds would be parametrised differently. A low incidence of job strain in the agro-ISN is preferable for the workers, however, the companies have to achieve this increase in job quality organisationally and financially.

In addition to the influence of the worker's character traits, the more stubborn workers are, the higher resulting power they have. There is a significant difference in the power of stubborn workers and workers that are adapting easily in terms of their level of trust. The higher the level of power of the workers, the more they feel secure in the job they currently have and therefore do not have the desire to change to a new job, join requalification training, join the union or participate in a strike. An average higher power of the workers could result in fewer costs for the agro-ISN and union in terms of job quality and requalification trainings.

Although the difference between the modelled behaviour for different threshold values for commitment is not significant; the higher the average commitment of the workers, the longer they stay at their current job.

The last emergent pattern analysed is that quickly satisfied workers can be seen as workers with a low ambition; their skill level is much lower than workers who are not so easily satisfied. A lower average skill level results in a higher unemployment rate and a higher percentage of vacancies, which is undesired for both workers and agro-ISN. The agro-ISN needs, at least a partly ambitious workforce in order to operate with a local workforce.

Second, the main model question shall be answered: ***How is the current Norte Fluminense sugar industry workforce affected by, and affects, the proposed agro-industrial symbiosis network in terms of (lack of) employment, job quality, skill level, status and power?***

From the exploration of the current and proposed scenarios, a comparison can be made between the two, concerning the (lack of) employment, job quality, skill level, and status and power. The current scenario can be seen as a business as usual scenario, in which no interventions are done; the proposed scenario is the desired scenario for the development of the Norte Fluminense region with an agro-ISN.

The Norte Fluminense workforce is positively influenced by the proposed agro-ISN and also positively influences the proposed agro-ISN, especially compared to the business as usual scenario. Power and status have a significantly greater increase in the proposed scenarios than in the current scenario, where for both scenarios different methods are used to simulate the market dynamics, i.e. the rate at which new companies are founded and existing companies go bankrupt. This is the result of an average skill increase of the workers, which in turn is caused by the availability of requalification train-

ings for the sugar industry workers. In the current scenario, no requalification trainings are organised, because the incentive for these trainings come from the development of the agro-ISN, which is absent in the current scenario.

Job strain declines significantly more in the proposed scenarios compared to the current scenarios, as a consequence of the new biorefineries and other industries that are founded in which the workers experience no job strain. However, the main reason for a better overall job quality is the union that negotiates with the companies. In the current scenario, the working conditions improve only because of the negotiations of the union.

Unemployment drops in the proposed scenarios but can rise again because of the lack of further ambition of the workers to acquire more skills. However, the latter could be more a feature of the formalisation of the model than what would be encountered in a real-world system. In the model, the workers are only created once and in the real world other people would, for example, grow older and join in the workforce with plenty of ambition to learn new skills. On the other hand, in the current scenario, there seems to be an increasing mismatch in the skills of workers and the skills required when companies are going bankrupt and newly found companies are trying to find employees. This can be explained because of the lack of skills of the workers in this business as usual scenario. Furthermore, if the current situation continues, the jobs that are available for the low-skilled workers will disappear at a quick rate, and will not be replaced with other low-skilled jobs.

Finally, the vacancies of the companies in the model increase, because of the same reason the unemployment rises again. The newly found companies that supply these vacancies cannot seem to find new employees because they are satisfied with and committed to their job at that time.

In order to be able to affect the workers positively, the agro-ISN, government, union or any other interested party should provide the necessary education for the workers to increase their skills, because there is a skills gap between the current and proposed industry. From analysing the differences between the business as usual and proposed scenarios, it becomes clear that the requalification trainings are the prerequisite for developing an agro-ISN with the current industry workers, in the context of the case study. As is found in a recent news article, it is most likely that the union, in collaboration with an educational institution, will provide this education.

Third, insights from the literature review in chapter 2, and model results in the current chapter, are concluded in the final sub-research question: ***What insights does the case study provide with regards to the interaction between an industry-revitalising industrial symbiosis network, the circular economy and its local workforce?***

Depending on the specific situation, the local workforce can benefit from the development of an ISN. When an industry is in decline, IS can revitalise that industry by making products and by-products more valuable, as proposed by Santos and Magrini (2018). This provides the local workforce with more opportunities to work. The resulting jobs are more resourceful than demanding and require a high skill level. Therefore, a skills gap might arise between the skills of the current industry workforce and skills required for the jobs; this gap calls for additional measures. For example, requalification subsidies could be implemented to provide workers with the necessary education. In the studied case, the requalification of workers in the sugar industry has proved to be successful to such a degree that there are 8,000 free training courses offered in April 2018; amongst others provided by the sugar industry union in Norte Fluminense, SISERJ.

In order to maintain the resources and knowledge inside the region - which is especially important in the case study because the aim of the agro-ISN is to develop the region sustainably - the companies are advised to hire from the workforce of the existing industry. Why would companies benefit from hiring locally? In combination with the requalification trainings, the current sugar industry workers have the ability to work in one of the ISN companies. From the company's perspective, they need the local support to promote social relationships and to develop a mutual trust between the key personnel of the ISN. Another reason to hire locally is that local growth has significant positive effects on labour markets. However, investigations should be done on the availability of and skills of the workers. The case study model is formalised as such, that a workers shortage results in a decrease in the productivity of the companies. However, in the studied case, the decrease in productivity only influences the profitability of the company and not the interaction between the workforce and the ISN.

Figure 7.6 visualises an optimistic outcome of the case study - in terms of IS development - of the

interaction between an industry revitalised through IS and its local workforce. The party that initiates the development of the agro-ISN (4), and thus the IS exchanges, is considered as undefined since Santos' proposal looks into the potential from the technological and not from the organisational side. For the studied case, it is recommended that the initiative for IS exchanges comes from supply chain businesses, unions, and/or non-governmental organisations; however, the most appropriate party for initiating IS exchanges differs per case. Therefore, the same icon is used for the party that initiates, and funds, the education needed to fill the knowledge gap mentioned before (bottom number 4 in figure 7.6). With the initiative of new IS businesses (3), the trust level (5) of the current sugar industry workforce (2) is increased. Through this increase in trust, local support of the workforce enables the initiators of the IS exchanges to find (6) and establish more exchanges (10); and an agro-ISN (8) is developed with the local (future) workforce (7). More companies in the agro-ISN create more and better quality jobs for the local workforce and again generates more trust and local support for the IS exchange initiators. However, this positive loop is only established with the right kind of education (9) for the workforce, to be able to fill the knowledge or skills gap. Motivations for funding and organising this occupational education can include economic, corporate social responsibility, and sustainable development reasons. It can be debated whether the initiator of the IS exchanges (4) should also be organising the education necessary to include the local workforce in the development of an ISN. From the case study analysis, it is advised that this party is, or these parties are, joining in the organisation and planning of the ISN and that the inclusion of the local workforce is included in the social pillar of sustainable development.

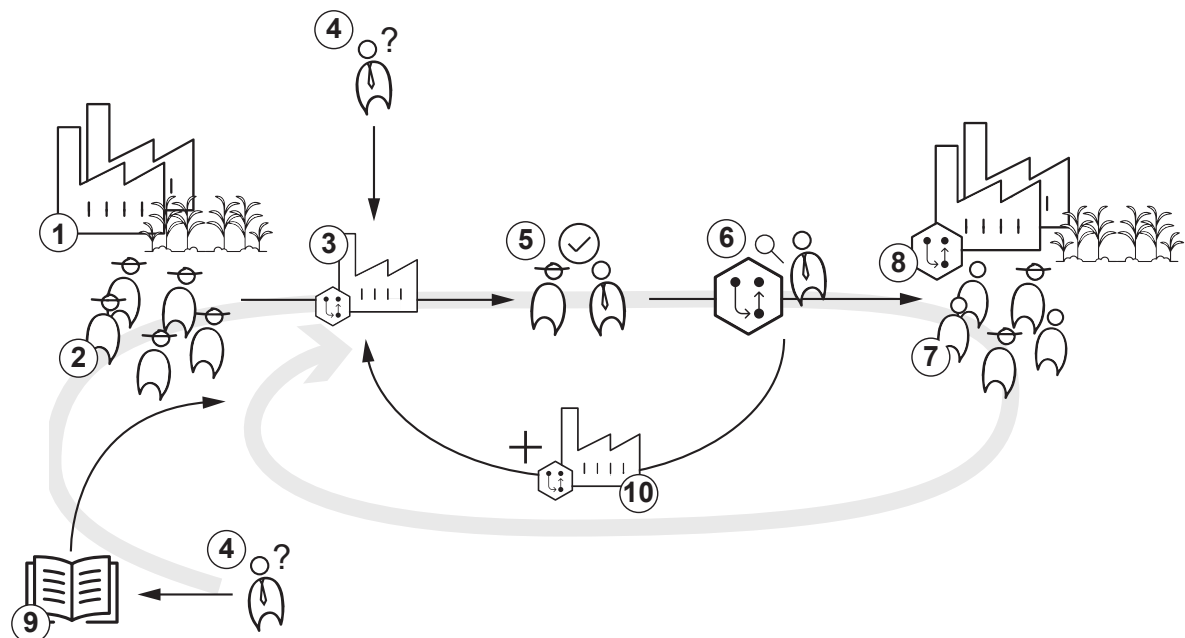


Figure 7.6: Optimistic IS development - interaction with the local workforce: insights from the case study. 1 = sugar industry; 2 = sugar industry's workforce; 3 = industrial symbiosis; 4 = initiator of the IS exchanges for an agro-ISN; 5 = trust of others; 6 = investigation of new industrial symbiosis exchanges; 7 = the potential future agro-ISN workforce; 8 = the proposed agro-ISN; 9 = education.

In researching the interaction between an industry-revitalising ISN, the CE and its workforce, it is important to include the whole system in which that workforce lives and operates. In the case study, the union plays an important role in the success or failure of workers that are potentially employed in new industries. The union organises the requalification trainings and attempts to create better working conditions for all of the jobs in the revitalised industry, which establishes the incentive for a higher commitment of the workers. In turn, that higher commitment leads to loyal employees in the ISN.

The circular economy should, following the definition by Murray et al. (2017), maximize human well-being. The workers are involved in the production, procurement, and reprocessing of goods and services which Murray et al. (2017) think should be designed and managed as both process and output. With this thesis' model and the proposed agro-ISN of Santos and Magrini (2018), the worker's well-being on the work floor is maximised, however only theoretical. Workers that experience a high well-

being on the work floor are said to have a better working performance than people who experience a low well-being in their job. Furthermore, workers with a high well-being are better in maintaining social relationships in general. This can be coupled to the cases researched by Hewes and Lyons (2008) on champions and the role of trust in EIPs: interaction with the community and local support proved key in developing social relationships that lead to IS exchanges. It could be easier to develop a connection with the local workforce with workers that have a better ability to develop and manage social relationships. In turn, this could lead to more local support and an enhanced development of an ISN.

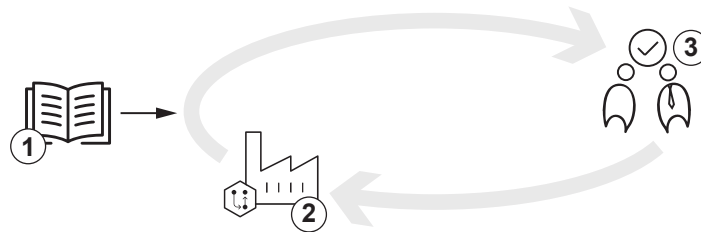
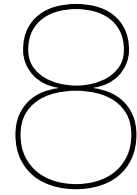


Figure 7.7: Insights of the case study applied to the circular economy concept. 1 = the appropriate education for enabling the industry's current workforce to change with that industry; 2 = industrial symbiosis; 3 = trust of others.

Improving the well-being of the workers of an industry in decline could lead to the realisation of IS exchanges with other industries. As a consequence, the (by-)products could become more valuable and therefore might attract more industries. If proven successful, the ISN in the case study could help to define local or regional methods and goals for the CE concept. Still, there is a prerequisite for such successful emergence, as shown in figure 7.7, the appropriate education (1) should be supplied in order to create a positive loop. In this loop, the trust of a workforce (3) is increased by the aforementioned education, which in turn enables the creation of more IS exchanges (2), or when applied to the CE concept the increased trust can enhance the circularity (2) of products and services between companies. Furthermore, supposing the industry is successfully revitalised, the Norte Fluminense case can serve as a starting point for investigations into IS as a revitalisation method for existing industries. Following Boons et al. (2011), the emergence of new systems from existing ones is needed for system change. For now, the studied case can serve as an addition to the few studies that have been conducted on the implementation of agricultural industries.

Although an ISN is a small part of the CE as it is thought of for the future, following Murray et al. (2017), workers should benefit from being employed in a CE participating company. The aim of the CE concept and IS is to handle waste in a useful way, and workers and companies should be able to benefit from these innovations economically, environmentally and socially.



Discussion and recommendations

This chapter consists of the discussion of the results (section 8.1) and recommendations for further research and application of this thesis (section 8.2). Even though it might be more common in research to list the final conclusions and then make recommendations, for this research the conclusion partly builds on the discussion. Therefore, chapter 9 involves the final conclusion.

8.1. Discussion

A literature review concerning the influence of IS on their workforce and vice versa showed that there is still research required on the subject. Because of collaboration with Santos, the choice was made to investigate this research gap with the case of the workers of the sugar industry in Norte Fluminense, Brazil. The case study serves as a proof-of-concept as it is built on a proposed situation with parameters that cannot currently be calibrated with real-world data. However, the case study could be considered as the start of more research towards the influence of an ISN on their (potential) workforce and vice versa, with real-world data. With this in mind, the discussion of this thesis ranges widely from the theories and their application to the conceptualisation of the case study and its outcomes, to the application of the results to ISNs and the CE. However, first, the consultation of FERAESP employees knowledgeable of the Brazilian sugar industry is introduced.

Expert consultation Typical agent-based model validation focuses on the usefulness and persuasiveness of the model to its users (van Dam et al., 2013), whereas the results of an ABM are the increased knowledge and insights in the studied system. These results and the conceptualisation of the model have been presented to Mr Carmo and Mr Galdino, respectively from communication and internal relations and socioeconomic studies at FERAESP - the Federation of Salaried Employees of the state of São Paulo. Contact with the Brazilian unions about the union membership rate generated their interest in this thesis research. As they are currently investigating violations at all sugarcane plants in the state of São Paulo, and are completely involved in the sugar industry in Brazil, they can be considered a valuable and trustworthy source of information.

Given the many uncertainties in the model, without the use of real data, and inescapable time constraints, this seemed the most valuable way to gain expert insights into the case study. The correspondence between this thesis' author and Mr Carmo can be found in appendix N and will be referred to as Carmo and Galdino (2018).

Theories and their application The theories that are used to represent the agents in the case study are chosen because of the specific context and history of the sugar industry workers. However, two of the three main theories applied - the status and power theory (Kemper, 2006) and the human behaviour modelling theory (Pahl-Wostl and Ebenhöh, 2004) - are not specifically made for the context and history of the case study. These could be applied to conceptualise similar agent-based models that research the interaction between employees and their workplace, potentially in an ISN.

Status and power can be of great importance for employees in any culture, in any type of industry. For example, even in flat hierarchical organisations in a democratic country like the Netherlands, a

comparatively egalitarian society, people act according to the perception of their own and other's status and power. In the model, the status and power of the workers are considered inadequate at the start; for applications to other situations this does not have to be the case and the configuration of the worker's perceptions of status and power can be adjusted accordingly. Furthermore, the power and status theory (Kemper, 2006) considers much more actions that one takes considering their perception of status and power than the actions that are applied to this thesis' case study. From all of those actions, there is a big chance that some will fit the specific context and history of any future case studies researched with this thesis' model.

The human behaviour modelling theory distinguishes nine different attributes of people that could influence their decision-making. From these nine attributes, two are chosen that are considered most important for the studied case. Pahl-Wostl and Ebenhöh (2004) make some recommendations concerning the application of their theory, for example, to randomize the levels of the attributes of the agents. However, there are no strict steps to follow, for example, for creating the heuristics that are used for the agent's decision-making. Therefore, with sufficient knowledge of the case where a potential new model is conceptualised for, one should be able to pick out the relevant attributes and make accompanying heuristics and learning experiences. These can, like in the thesis, easily be combined with other theories.

The final theory used for the conceptualisation of the case study, the theory of frames of references and fields of opportunities from de L'Estoile (2014), is specific for this case and thus might only apply to situations with similar industries and similar cultures. Case-specific theories can in the future always be combined with the two above-mentioned theories, like is done in this thesis.

While these theories form the basis of the model, a different perspective could have lead to a whole different conceptualisation of the same case study. If, for example, the opportunity cost theory was used, the workers would have had an economical perception and the model would have probably been dominated by choices that involve calculating the economic value of the different options that the workers have. The outcomes of this thought experiment model would involve economic drivers for the choices that the workers make. As other economic models, this does not involve the human factor such as health and mental well-being, which is included in this thesis' model and is considered by de L'Estoile (2014) as the appropriate method to analyse the lives of the sugar industry workers. In the next paragraph is discussed how the case study is conceptualised and formalised.

Conceptualisation and formalisation First, the conceptualisation of the model is discussed on the basis of the expert consultation. Second, more issues concerning the conceptualisation and formalisation that are found during the thesis project are explained.

After expert consultation, it became clear that the Brazilian government is not realistically represented in the model, specifically the subsidies that they would provide. Carmo and Galdino (2018) state that the national government does not have any incentive to improve the worker's conditions, especially nowadays with the reform of labour laws. For the model, this could result in different actors that would finance, for example, the requalification trainings. Actors that already have been involved in financing and organising the requalification of the workers of the sugar industry in Brazil are (international) development funds, companies in the supply chain, workers and trade unions and other non-governmental organisations.

Another difference between the model and the empirical observations of Carmo and Galdino (2018), is the dependence of the workers on their jobs. As argued by Carmo and Galdino (2018), "the workers undergo any type of work because they depend on them to survive". These types of work can be informal, illegal and even resemble slavery, which means that they do not have any defined rights. This critical aspect of the lives of the sugar industry workers might not be sufficiently expressed by the current model. If the workers are, for example, fired from their job, they might not look for a new job, depending on their level of status, power, trust and commitment. This could in the real-world system be caused by, for example, crime, addiction, or emigration.

Furthermore, in the model the productivity is linked to the number of vacant jobs in a company, and whether the company is experiencing a strike or not. However, as stated by Carmo and Galdino (2018), the productivity of the companies is especially linked to the incorporation of technologies such as automation, rather than only associated with the skills of the workers.

Some issues concerning the implementation of the model became clear after the formalisation phase

was concluded, especially about the formalisation of the hiring subsidies. This was not implemented as was described in the literature with real-world examples. The hiring subsidies would have represented the real-world more accurately if, for example, only workers with a specific range of skill level could be hired with those subsidies. Furthermore, the workers should be given the incentive to apply for jobs with hiring subsidies and not just any job that is within the reach of their skill level - which is now the case.

The skills that are acquired by the workers in the current model are general skills and applicable at farms, mills, biorefineries and other industries, i.e. all the possible company types in the agro-ISON. A more specified skill-set could have been implemented, which is more comparable to the RenovAção project or the latest free courses that are going to be offered in April 2018 in Norte Fluminense.

Case study outcomes The emergent patterns derived from the case study are thought to be plausible, but from the author's personal perspective - which deviates greatly from the perspective of the subjects in the case study. Although experts on the subject also have biases and incomplete knowledge, consultation of those experts is of great value if further research on this subject is conducted. By obtaining multiple perspectives on a system the level of uncertainty can be reduced.

Concerning the job quality of the sugar industry, it can be debated whether working outside on the sugarcane farms with improved working conditions or inside in biorefineries or other industries is better for the workers' well-being. However, compared to the current working conditions at the sugar farms in Norte Fluminense, it is better to work inside because this is a much more controlled environment, i.e. the working conditions can be regulated more. Adding to this, biorefineries are often high-tech, which usually allows for better working conditions (Harpaz and Meshoulam, 2004).

Results of the case study are used to gain insights into the interaction between IS and its workforce in general. In order to use such a specific case study to gain broad insights, many assumptions must be made in terms of the application of the theories that support those insights in a broad view. An example of this extrapolation is the argument that a high well-being of employees improves their working performance. The lack of comparable case studies calls upon comparing the thesis with other cases in similar circumstances, such as comparing the social interaction between key personnel of ISNs with the social interaction between the ISN companies and their employees. The more assumptions that must be made, the more uncertain the application of the thesis in a broad perspective is. Therefore, conclusions must be made very specific.

Insights from the case study applied to industrial symbiosis and the circular economy The insights gained from the studied case can be extrapolated to industrial symbiosis and the circular economy concept. Those insights include that the appropriate education should be supplied when an industry is aimed to be revitalised through industrial symbiosis; which would also account for the circular economy since an ISN could be a part of, and an example for a circular economy. Appropriate education can relate to, amongst others, on-the-job learning, general education and job-specific skills, but must be specified per case. From the results of the model, it becomes clear that (continuous) education of the whole working population is essential to enable the transition of an industry.

Expanding the application of the model The case study is modelled such that the companies representing the agro-ISON could also be businesses in a conventional industrial park. There are no waste or by-product flows, unlike in Santos' model. The emergence of an agro-ISON which could be the result of these cheap flows of resources is represented in the model by a simple increase in the number of companies. This could alternatively be thought of as a new business park with attractive features like cheap rent. With this perspective in mind, one could think of the model as an approach to gain insights into the effects of a changing industry on its local workforce and vice versa. However, and this is not represented in the model, employees in an ISN could have a greater knowledge and more incentive for exploring new business models that use available waste streams in their industry of employment.

The combination of this thesis' model with Santos' model which does explicitly represent the resource exchanges of an ISN, would not make a difference for the recommendations one would be able to give from insights of the combined model. The workers would still not be able to, for example, create their own business with resources from the other industries. This can be interpreted as, like mentioned before, that the model is more generally applicable than only for ISNs, and that it might not matter for the workforce of an industry in what configuration that industry is functioning. For example, biorefinery

employees will only experience differences in their daily working life concerning the tasks they need to perform at work for e.g. preparing waste as a resource input for another industry or preparing waste for disposal. These tasks could change over time, but this can also be the case for conventional industries that are not considered as an ISN but are undergoing change for other reasons. Current examples of changing industries that influence their workforce are the autonomous trucks that are developed for the logistics sector, continuous further automation of producing industries and artificial intelligence implementation in, for example, the translation service sector.

When the model is considered as generally applicable to obtain insights in the interaction of a workforce and the changing industry in which they are employed, it would be of great relevance to the circular economy. As the circular economy concept is one that the current industries might transition towards, this change for the current workforce could be investigated through this thesis' model.

8.2. Recommendations

This section distinguishes two kinds of recommendations: firstly, the recommendation for follow-up research is elaborated on, and secondly, recommendations for the actors in the case study are set out.

Follow-up research The research could be followed-up with field-work investigations of the people that work in the sugar industry in Norte Fluminense. More insights could be gained for another iteration of the conceptualisation and formalisation of the model. Moreover, real data could be used from questionnaires, interviews and observations to provide the parameters with more realistic values. Other institutions that could be researched are the government and their political agenda and large multi-nationals that utilise the sugar from the sugar industry and their drivers for change. Furthermore, the motivations of the current sugar industry to transition towards the circular economy could be analysed.

When looking at the field of social simulations, this model could serve as a start to a wide range of models that aim to research cases with socially equipped agents. The GRASP theory of Hofstede (2015) could be extended in the model of this thesis; especially adding more of the cultural values is thought to improve the current model, e.g. values on corruption and (non)compliance with regulations. However, the incentives and drivers of the subjects must not be forgotten. As Cristiano Augusto Galdino from FERAESP states, some workers take on any possible job to survive, and these kinds of key aspects must also be taken into account.

The model and method used could be refined and applied in different contexts; as mentioned before, the two main theories are generally applicable. Because of the great complexity of current systems, there is a demand in the scientific world for more realistic studies on human capital in the industrial context. To grasp that great complexity, these studies should be approached from a multidisciplinary perspective.

Advice for the actors in the Norte Fluminense case When the government would have been involved in the development of the proposed agro-ISN in Norte Fluminense, it would have been advised for them to provide requalification trainings for the sugar industry workforce. However, this is realistically not the case, so this advice is redirected to the union and the companies in the agro-ISN. The union and companies could organise the requalification trainings in collaboration with an educational institute such as SENAI. In order to organise the trainings to be compatible with the newly created jobs, the companies in the agro-ISN should be involved from the start. On the one hand, the companies must be convinced that they are needed in the organisation of these trainings, but on the other hand, supply chain companies in the sugar industry have been involved in the retraining of their workers before. To attract workers, the trainings should be given free of cost and workers should be able to continue earning their wages whilst in training.

For the workers, it is advised to invest in education, if possible, and to trust the new companies in the changing sugar industry. Investments in education could account for the workers themselves, or for their family and friends. Education could also be obtained through family and friends, and it is encouraged to make use of all possibilities, i.e. their fields of opportunities.

For the workers, companies and union it is advised to have an open attitude to change. Whoever is the initiator and planner of the proposed agro-ISN, all parties involved should be able to see the benefits from the transition that is aimed to revitalise the sugar industry. The worker's attitude in terms

of trust or commitment influences greatly the reciprocity towards their employees and whether they want to obtain new skills or find a new job.

The final advice to the companies calls upon the provision of jobs for a wide range of skills, as is analysed from the model results.

9

Conclusion and reflection

This thesis research is concluded in section 9.1 by attempting to answer the main research question. A personal reflection is elaborated on in section 9.2.

9.1. Conclusion

This thesis is concluded by answering the main research question posed in chapter 1. Together with the conclusions at the end of chapters 2, 4 and 7, it attempts to fill the knowledge gap stated in the introduction. The main research question is:

How is the workforce of an industry affected by, and affects, the revitalisation of that industry through industrial symbiosis?

Insights from literature show that the relation between the employer, employee, and the local community is of great importance for the successful emergence of an industrial symbiosis network. Companies that want to initiate IS exchanges benefit from local support in terms of their enhancement in the social relationships they want to engage in with potential IS industries. Furthermore, a successful ISN requires a certain degree of reciprocity and trust between employers, which is developed over time and with personal meetings. When such relationships are established strongly and professionally, IS can enhance the social equity within communities. As a result, the communities share a sense of collaboration and responsible orientation.

The insights from the case study are visualised in figure 9.1, in order to achieve the research aim. The workforce (4) of an industry can be positively affected by the revitalisation (3) of that industry (2) through industrial symbiosis (1). This positive effect is reached in terms of an increase in satisfaction (6) of the workers because they have the ability to work under better conditions and have potentially learned new skills. Furthermore, positive effects from the revitalisation of the industry on its workforce that return as positive effects from the workforce on the revitalisation of the industry through industrial symbiosis, are the increase of the worker's commitment (7) and trust (8). A workforce that is committed to what they do and has a general high trust of others can give the local support that is needed for the key personnel of an ISN to establish IS exchanges. In turn, this enhances the revitalisation of the industry, which means more jobs are created, and the satisfaction, commitment, and trust of the workforce are increased more. To establish this positive loop, the appropriate education (5) is needed, which depend greatly on the context and history of the industry that is revitalised. For example, in the case study especially the skills gap, poor working conditions and employer-employee power relations have been addressed as important contextual and historical characteristics of the system. Furthermore, the organisation of providing the education is of great importance, for the studied case, more requalification trainings - which could be assumed as achieving better results - resulted in a mismatch between skilled workers needed and skilled workers available. Without education and the right implementation of the education, a knowledge or skills gaps, job and skills mismatching, or a lack of incentive from the workforce would hamper the revitalisation of the industry.

The design of the education needed to involve the local community in the development of the in-

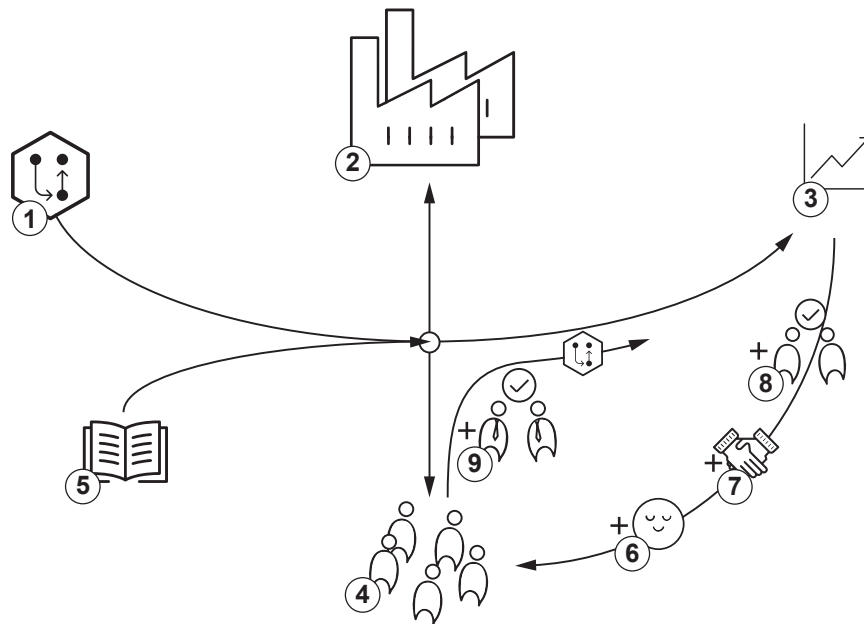


Figure 9.1: A optimistic view on the final conclusion. 1 = industrial symbiosis; 2 = an industry; 3 = revitalisation; 4 = an industry's workforce; 5 = the appropriate education; 6 = satisfaction; 7 = commitment; 8 = trust; = trust of industrial symbiosis network company managers.

dustrial symbiosis network should include institutions relevant for the working life of that community. With regards to the case study, this is the union of the regional sugar industry. However, consultation of experts is required to grasp the real influence that these institutions have, which can differ greatly from literature analyses.

With regards to the planning of an industrial symbiosis network that aims to revitalise an industry, the characteristics of that industry need to be taken into account. As analysed in the case study, which includes an agricultural low-mechanised industry in decline and where a large part of the jobs is low-skilled, the proposed agro-industrial symbiosis network should still provide a great diversity of jobs which require a wide range of skill level. Biorefineries provide that need for a wide range of skills required for jobs; because of their substantial need for feedstock, agricultural jobs are essential - however mechanised or manual. In addition, the technologies used in biorefineries range from mechanical to (bio)chemical processes; even within the biorefinery, there is an availability of low-skilled and high-skilled jobs.

Going further into the planning of an industrial symbiosis network, the industry that is aimed to be revitalised should change gradually in order to include the workforce of that industry. The education that needs to be provided much be synchronised with the rate of jobs created by the emergence of the ISN, to avoid unnecessary mismatching in skills required and skills of the workforce available.

Similar to findings in the literature on the role of trust in emerging industrial symbiosis networks, a conclusion can be drawn from the emerging patterns that are revealed through analysis of the case study. The trust of the workforce in a revitalising industry is increased when they gain the ability to acquire more skills and consequently increase the chance to work somewhere with better working conditions. In addition, better working conditions - and an increase in the workers' well-being - may increase the workers' commitment, which in turn can result in low unemployment and low vacancies. The industrial symbiosis network benefits from these increases of trust and commitment through the support of the workforce in terms of social relationships.

The win-win-win situation in terms of economic prosperity, environmental integrity and social equity that is said to be gained through IS, is as of yet far from being researched in real-world systems. From an incomplete range of future possibilities as analysed from the case study, social equity in the sugar industry can be improved. Especially concerning the power and status relations between workers and their bosses with a history of slavery, big improvements can be made with the development of an industrial symbiosis network. As mentioned before, satisfactory working conditions and an improved

well-being of the workers benefit the company in which they are employed. In this sense, the workers and the industrial symbiosis network can positively influence each other as in a symbiotic relationship.

This final remark involves an aspect that has great influence on how a workforce can affect the revitalisation of an industry through industrial symbiosis, and vice versa: education. Education is key to involve people in changing industries, but the question is, who is responsible for providing this education? And who benefits most from providing this education? These questions should be asked before revitalising an industry through industrial symbiosis with the inclusion of the local workforce.

9.2. Reflection

From the beginning of this thesis project, the case study and modelling method has really grabbed my attention and interest. Although there were some times where less work could be done than was my intention, all in all, I am quite satisfied with the results.

The search for the knowledge gap and proposal at the beginning of the thesis was especially characterised by the absence of knowledge and from my side, being lost in the social sciences. What always helped me a lot was being in contact with others, if it were professors from the TU Delft or another university, PhD students, or in the final phase the worker and trade unions in Brazil. For example, the GRASP theory of Gert Jan Hofstede which served as the base of one of the main theories used, I could never have found without Igor Nikolic giving me his contact information and pointing me in his direction. The paper which described his theory was not yet published. Furthermore, outside the very useful meetings with my supervisors, all the meetings with Victoria Santos, Jorge Moncada, Caspar Chorus have always helped if I was stuck or needed advise.

To take on agent-based modelling as thesis tool with only a very basic level of understanding and even less experience with the tool was a challenge. I noticed especially towards the end of the project, where the decision must be made for which experiments must be run and which results were expected, that this was completely new to me. A lot of repetition has finally enhanced my understanding and my perception of the importance of the last steps of the ABM process. If I had known this in the beginning, I would have planned more time for it in advance.

Furthermore, what I did realise at the start of this thesis but am very consciously aware of now, is that such a big project requires linking all the information together. What is known in the beginning must relate to the end-results, and this can cause a lack of oversight. By visualising the information I like to gain back the oversight, however, there is not always enough time to do so. What I have learned from this, is that also thinking and understanding of the information gathered and produced must be included in a planning.

All in all, I have learned a lot from this thesis and thanks to Igor's reflections on my work, also about myself.

Bibliography

- Abreu, de, R. L. (n.d.). Rio de janeiro meso norte fluminense.
- Agarwal, M. A. and Strachan, P. (2006). Literature review on eco-industrial development initiatives around the world and the methods employed to evaluate their performance / effectiveness A Report Prepared for Databuild. Technical report, The Robert Gordon University.
- Ajzen, I. (1991). The theory of planned behavior. *Organizational behavior and human decision processes*, 50(2):179–211.
- Arbache, J. S. (2008). Unions and the labor market in brazil. *Brazil in Focus: Economic, Political and Social Issues*, pages 123–54.
- Ashton, W. S. and Bain, A. C. (2012). Assessing the "Short Mental Distance" in Eco-Industrial Networks. *Journal of Industrial Ecology*, 16(1):70–82.
- Bansal, P. and Mcknight, B. (2009). Looking forward, pushing back and peering sideways: analyzing the sustainability of industrial symbiosis. *Journal of Supply Chain Management*, 45(4):26–37.
- Bartik, T. J. (1991). Who benefits from state and local economic development policies?
- Binder, C. R., Hinkel, J., Bots, P. W. G., and Pahl-Wostl, C. (2013). Comparison of Frameworks for Analyzing Social-ecological Systems. *Ecology and Society*, 18(4):art26.
- Bonabeau, E. (2002). Agent-based modeling: Methods and techniques for simulating human systems. *Proceedings of the National Academy of Sciences*, 99(suppl 3):7280–7287.
- Boons, F., Spekkink, W., and Mouzakitis, Y. (2011). The dynamics of industrial symbiosis: a proposal for a conceptual framework based upon a comprehensive literature review. *Journal of Cleaner Production*, 19(9-10):905–911.
- Brown, A. J., Merkl, C., and Snower, D. J. (2011). Comparing the effectiveness of employment subsidies. *Labour Economics*, 18(2):168–179.
- Brundtland, G. H. (1987). Our Common Future: Report of the World Commission on Environment and Development. Technical Report 1, World Commission on Environment and Development.
- Buchanan, J. M. (1991). *Opportunity Cost*, pages 520–525. Palgrave Macmillan UK, London.
- Carmo, A. and Galdino, C. A. (2018). Feraesp validation. by email.
- Castro, R. A. R. D. (2009). *Cooperacao em aglomeracoes produtivas: estudo de caso do setor sucroalcooleiro fluminense*. PhD thesis.
- CEPEA. Indicador semanal do etanol hidratado combustível CEPEA/Esalq - São Paulo. Technical report, CEPEA - Centro de Estudos Avançados em Economia Aplicada.
- CEPEA (2017). Açúcar | Indicador do açúcar cristal CEPEA/Esalq - São Paulo. Technical report, Centro de Estudos Avançados em Economia Aplicada - CEPEA-Esalq/USP.
- Chase, J. (1999). Trapped workers, urban freedoms and labor control in brazilian agriculture: Evidence from southwest goiás. *Journal of Rural Studies*, 15(2):201–220.
- Chertow, M. and Ehrenfeld, J. (2012). Organizing Self-Organizing Systems. *Journal of Industrial Ecology*, 16(1):13–27.
- Chertow, M. R. (1998). The Eco-industrial Park Model Reconsidered. *Journal of Industrial Ecology*, 2(3):8–10.

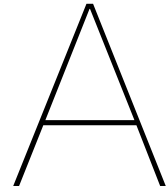
- Chertow, M. R. (2000). Industrial Symbiosis: Literature and Taxonomy. *Annual Reviews Energy Environment*, 25:313–337.
- Chertow, M. R. (2007). “Uncovering” Industrial Symbiosis. *Journal of Industrial Ecology*, 11(1):11–30.
- Chertow, M. R., Ashton, W. S., and Espinosa, J. C. (2008). Industrial symbiosis in puerto rico: Environmentally related agglomeration economies. *Regional studies*, 42(10):1299–1312.
- Cherubini, F. (2010). The biorefinery concept: Using biomass instead of oil for producing energy and chemicals. *Energy Conversion and Management*, 51(7):1412–1421.
- Clark, J. H. and Deswarte, F. (2015). *Introduction to chemicals from biomass*. John Wiley & Sons.
- COAGRO (n.d.). Setor sucroalcooleiro em recuperação. <http://www.coagro.coop.br/post/81>.
- Coelho, S. T., Goldemberg, J., Lucon, O., and Guardabassi, P. (2006). Brazilian sugarcane ethanol: lessons learned [1]. *Energy for sustainable development*, 10(2):26–39.
- Cohen-Rosenthal, E. (2000). A walk on the human side of industrial ecology. 44:245–264.
- CONAB (2015). Séries Históricas de Área Plantada, Produtividade e Produção, Relativas às Safras 1976/77 a 2014/15 de Grãos, 2001 a 2014 de Café, 2005/06 a 2014/15 de Cana-de-Açúcar.
- Coslovsky, S. V. and Locke, R. (2013). Parallel paths to enforcement: Private compliance, public regulation, and labor standards in the brazilian sugar sector. *Politics & Society*, 41(4):497–526.
- Couto Mantese, G. and Capaldo Amaral, D. (2017). Comparison of industrial symbiosis indicators through agent-based modeling. *Journal of Cleaner Production*, 140:1652–1671.
- da Industria, P. (n.d.). Senai. <http://www.portaldaindustria.com.br/senai/en/about/senai/>.
- de Itálva, F. (2018). Norte e noroeste fluminense: Sindicatos da indústria oferecem 326 vagas gratuitas em cursos do senai. <http://www.folhadeitalva.com.br/2018/01/norte-e-noroeste-fluminense-sindicatos.html>.
- de L’Estoile, B. (2014). Money is good, but a friend is better “uncertainty, orientation to the future, and the economy”. *Current Anthropology*, 55(S9):S62–S73.
- De L’Estoile, B. (2014). Money is good, but a friend is better “uncertainty, orientation to the future, and the economy”. *Current Anthropology*, 55(S9):S62–S73.
- Diener, E. and Seligman, M. E. (2004). Beyond money: Toward an economy of well-being. *Psychological science in the public interest*, 5(1):1–31.
- Doménech, T. and Davies, M. (2011). The role of embeddedness in industrial symbiosis networks: Phases in the evolution of industrial symbiosis networks. *Business Strategy and the Environment*, 20(5):281–296.
- Economia Agrícola UFRRJ (2017). Comportamento do preço de comercialização do açúcar no mercado interno do estado do Rio de Janeiro. Technical report, Universidade Federal Rural do Rio de Janeiro - Campus Campos dos Goytacazes (UFRRJ-Campos), Campos dos Goytacazes.
- Epstein, J. M. and Axtell, R. (1996). *Growing artificial societies: Social science from the bottom up*. Brookings Institution Press and MIT Press.
- FAO (2014). Faostat - fao’s corporate database. <http://www.fao.org/faostat/en/#data/QC>.
- Fernandez-Mena, H., Nesme, T., and Pellerin, S. (2016). Towards an Agro-Industrial Ecology: A review of nutrient flow modelling and assessment tools in agro-food systems at the local scale. *Science of the Total Environment*, 543:467–479.
- Fischhoff, B. and Small, M. J. (2000). Human Behavior in Industrial Ecology Modelling. *Journal of Industrial Ecology*, 3(2):4–7.

- Gibbs, D., Deutz, P., and Proctor, A. (2005). Industrial ecology and eco-industrial development: A potential paradigm for local and regional development? *Regional Studies*, 39(2):171–183.
- Goldemberg, J., Coelho, S. T., and Guardabassi, P. (2008). The sustainability of ethanol production from sugarcane. *Energy Policy*, 36(6):2086–2097.
- Harpaz, I. and Meshoulam, I. (2004). Differences in the meaning of work in israel: Workers in high-tech versus traditional work industries. *The Journal of High Technology Management Research*, 15(2):163–182.
- Hewes, A. K. and Lyons, D. I. (2008). The humanistic side of eco-industrial parks: champions and the role of trust. *Regional studies*, 42(10):1329–1342.
- Hinkel, J. and Bisaro, A. (2015). A review and classification of analytical methods for climate change adaptation. *Wiley Interdisciplinary Reviews: Climate Change*, 6(2):171–188.
- Hofsetz, K. and Silva, M. (2012). Brazilian sugarcane bagasse: Energy and non-energy consumption. *Biomass and Bioenergy*, pages 564–573.
- Hofstede, G. J. (2015). Grasp agents: social first, intelligent later.
- IBGE (2016). Brazil. <http://paises.ibge.gov.br/#/en/pais/brasil/info>.
- IEA (2008). Iea bioenergy task 42 on biorefineries: co-production of fuels, chemicals, power and materials from biomass. In: Minutes of the third Task meeting, Copenhagen, Denmark.
- Kay, J. (2002). On complexity theory, exergy and industrial ecology: some implications for construction ecology. In *Construction Ecology: Nature as the Basis for Green Buildings*, pages 72–107. London: Spon.
- Kemper, T. D. (1978). *A social interactional theory of emotions*. Wiley New York.
- Kemper, T. D. (2006). Power and status and the power-status theory of emotions. *Handbook of the sociology of emotions*, pages 87–113.
- Kemper, T. D. (2011). *Status, Power and Ritual Interaction: a Relational Reading of Durkheim, Goffman and Collins*. Ashgate.
- Kikuchi, Y. b. c. d., Kanematsu, Y., Ugo, M., Hamada, Y., and Okubo, T. g. (2015). Industrial Symbiosis Centered on a Regional Cogeneration Power Plant Utilizing Available Local Resources: A Case Study of Tanegashima. *Journal of Industrial Ecology*.
- Kitao, S., Şahin, A., and Song, J. (2011). Hiring subsidies, job creation and job destruction. *Economics Letters*, 113(3):248–251.
- Lifset, R. and Graedel, T. E. (2002). Industrial ecology: goals and definitions. *A handbook of industrial ecology*, pages 3–15.
- Lindström, M. (2009). Psychosocial work conditions, unemployment, and generalized trust in other people: A population-based study of psychosocial health determinants. *The Social Science Journal*, 46(3):584–593.
- Macedo, C. d. M. M. (2007). *Trabalhadores da cana-de-acucar de campos dos goytacazes: estrategias de sobrevivencia na entressafra*. PhD thesis, Universidade Candido Mendes.
- Macedo, I. d. C. (1992). The sugar cane agro-industry—its contribution to reducing co2 emissions in brazil. *Biomass and Bioenergy*, 3(2):77–80.
- Martinelli, L. A. and Filoso, S. (2008). Expansion of sugarcane ethanol production in brazil: environmental and social challenges. *Ecological Applications*, 18(4):885–898.
- Martinelli, L. A., Naylor, R., Vitousek, P. M., and Moutinho, P. (2010). Agriculture in brazil: impacts, costs, and opportunities for a sustainable future. *Current Opinion in Environmental Sustainability*, 2(5):431–438.

- McKay, M. D., Beckman, R. J., and Conover, W. J. (1979). A comparison of three methods for selecting values of input variables in the analysis of output from a computer code. *Technometrics*, 21(2):239–245.
- Miller, J. G. (1978). *Living Systems*. McGraw-Hill, New York, USA.
- Murray, A., Skene, K., and Haynes, K. (2017). The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context. *Journal of Business Ethics*, 140(3):369–380.
- OECD (2014). *Oecd employment outlook 2014*.
- OECD (2017a). Getting skills right: Skills for jobs indicators. http://www.keepeek.com/Digital-Asset-Management/oecd/employment/getting-skills-right-skills-for-jobs-indicators_9789264277878-en#page2.
- OECD (2017b). *Oecd employment outlook 2017*. http://www.keepeek.com/Digital-Asset-Management/oecd/employment/oecd-employment-outlook-2017_empl_outlook-2017-en#.WoF6cujOVpY#page4.
- Ohnishi, S., Fujita, T., Chen, X., and Fujii, M. (2012). Econometric analysis of the performance of recycling projects in Japanese Eco-Towns. *Journal of cleaner production*, 33:217–225.
- Ometto, A. (2000). *Discussao sobre os fatores ambientais impactados pelo setor sucro-alcooleiro e a certificacao socio-ambiental, Sao Carlos*. Dissertation, Escola de Engenharia de Sao Carlos. Universidade de Sao Paulo.
- Ometto, A., Ramos, P., and Lombardi, G. (2007). The benefits of a Brazilian agro-industrial symbiosis system and the strategies to make it happen. *Journal of Cleaner Production*, 15(13-14):1253–1258.
- Organization, I. L. (2018). *World employment social outlook*. http://www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/---publ/documents/publication/wcms_615594.pdf.
- Orszag, J. M. and Snower, D. J. (2003). Designing employment subsidies. *Labour economics*, 10(5):557–572.
- Pahl-Wostl, C. (2003). The importance of the human dimension in integrated assessment models and processes : Actor based analysis and modelling approaches. *Proceedings of the modelling and simulation society of Australia and New Zealand, MODSIM*, pages 465–472.
- Pahl-Wostl, C. and Ebenhöh, E. (2004). Heuristics to characterise human behaviour in agent based models. *iEMSs 2004 International Congress:*
- Pandey, A., Soccol, C. R., Nigam, P., and Soccol, V. T. (2000). Biotechnological potential of agro-industrial residues. i: sugarcane bagasse. *Bioresource technology*, 74(1):69–80.
- Papong, S., Rewlay-ngoan, C., Itsubo, N., and Malakul, P. (2017). Environmental life cycle assessment and social impacts of bioethanol production in Thailand. *Journal of Cleaner Production*, 157:254–266.
- Peixoto, L. S. (2005). *Reestruturação e revitalização do setor sucroalcooleiro da região Norte Fluminense: setor sucroalcooleiro da região Norte Fluminense*. PhD thesis, UNIVERSIDADE ESTADUAL DO NORTE FLUMINENSE.
- R Core Team (2013). *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria.
- Ribeiro, A. d. C. (2010). O setor sucroalcooleiro fluminense: erros de avaliacao.
- Rocha, F. L. R., Marziale, M. H. P., and Hong, O.-S. (2010). Work and health conditions of sugar cane workers in brazil. *Revista da Escola de Enfermagem da USP*, 44(4):978–983.

- Ruimax Viana Soares and Alcimar das Chagas Ribeiro (2013). Análise do declínio do setor sucroalcooleiro na região Norte Fluminense a partir da economia institucional. In *IX Congresso Nacional de Excelência em Gestão*.
- Ryan, A. J. (2008). What is a systems approach? Master's thesis, Cornell University Library.
- Sahakian, M. (2016). *The Social and Solidarity Economy: Why Is It Relevant to Industrial Ecology?*, pages 205–227. Springer International Publishing, Cham.
- Santos, E. V. M. and Lima, M. S. B. (2015). O rural no Norte Fluminense. Technical report, Enanpege.
- Santos, V. (2013). Proposta metodológica para criação de biorrefinaria de bagaço de cana produtora de bioplataformas químicas: um ensaio preliminar como parte de um sistema de simbiose industrial em campos dos goytacazes-rj. Master's thesis, Federal University of Rio de Janeiro, Brazil.
- Santos, V., Szklo, A., and Magrini, A. (2014). Building a "bio-perspective" from petroleum revenues: a pathway through bioplatforms' oriented biofineries in rio de janeiro state, brazil. In *Proceedings of the 21st World Petroleum Congress*.
- Santos, V. E. N. and Magrini, A. (2018). Biorefining and industrial symbiosis: A proposal for regional development in brazil. *Journal of Cleaner Production*, 177:19–33.
- Scholz, R. W. (2011). *Environmental Literacy in Science and Society: From Knowledge to Decisions*. Cambridge University Press.
- Shalizi Rohilla, C. (2006). Methods and techniques of complex systems science: an overview. *Complex systems science in biomedicine*, pages 33–114.
- Sigaud, L. (2008). A collective ethnographer: fieldwork experience in the brazilian northeast. *Social Science Information*, 47(1):71–97.
- Silva, M. A. M. (1999). Errantes do Fim do Seculo. Technical report, UNESP/ SP.
- Simboli, A., Taddeo, R., and Morgante, A. (2015). The potential of Industrial Ecology in agri-food clusters (AFCs): A case study based on valorisation of auxiliary materials. *Ecological economics*, 111:65–75.
- SISERJ (2016). Acompanhamento da Safra 2015/16. Technical report, Sindicato da Indústria Sucroenergética do Estado do Rio de Janeiro, Campos dos Goytacazes.
- Stahel, W. R. (2013). Policy for material efficiency—sustainable taxation as a departure from the throw-away society. *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences*, 371(1986).
- Taddeo, R., Simboli, A., and Morgante, A. (2012). Implementing eco-industrial parks in existing clusters. Findings from a historical Italian chemical site. *Journal of Cleaner Production*, 33:22–29.
- The American Heritage Science Dictionary (n.d.). adaptation. <http://www.dictionary.com/browse/adaptation>.
- Tiejun, D. (2010). Two quantitative indices for the planning and evaluation of eco-industrial parks. *Resources, Conservation and Recycling*, 54(7):442–448.
- TWB (2005). Comparative study on the distribution of oil rents in bolivia, colombia, ecuador, and peru.
- UNICA (2010). Sustainability report. <http://sugarcane.org/resource-library/books/Sustainability.pdf>.
- UNICA (2016). Sugarcane, ethanol and sugar production - 2016/2017 harvest season. www.unicadata.com.br/.
- Valenzuela-Venegas, G., Salgado, J. C., and Daz-Alvarado, F. A. (2016). Sustainability indicators for the assessment of eco-industrial parks: classification and criteria for selection.

- van Berkel, R., Fujita, T., Hashimoto, S., and Fujii, M. (2009a). Quantitative assessment of urban and industrial symbiosis in Kawasaki, Japan. *Environmental science & technology*, 43(5):1271–1281.
- van Berkel, R., Fujita, T., Hashimoto, S., and Geng, Y. (2009b). Industrial and urban symbiosis in Japan: Analysis of the Eco-Town program 1997-2006. *Journal of environmental management*, 90(3):1544–1556.
- van Dam, K. H., Nikolic, I., and Lukszo, Z. (2013). *Agent-Based Modelling of Socio-Technical Systems*. Springer.
- Wainwright, J. and Mulligan, M. (2005). *Environmental modelling: finding simplicity in complexity*. John Wiley & Sons.
- Wilensky, U. (1999). *Netlogo*. Center for Connected Learning and Computer-Based Modeling.
- Winans, K., Kendall, A., and Deng, H. (2017). The history and current applications of the circular economy concept.
- Wójtowicz, M. (2016). Spatial expansion and social and economic development of the Brazilian Megalopolis between Rio de Janeiro and São Paulo. In *Vulnerabilidad territorial ante la expansión urbana*, pages 501–519. Universidad Autónoma del Estado de México, 1 edition.
- Wooldridge, M. and Jennings, N. (1995). Intelligent agents—theory and practice. *Knowledge Engineering Review*, 10(2):115–152.
- Yap, N. T. and Devlin, J. F. (2017). Explaining Industrial Symbiosis Emergence, Development, and Disruption: A Multilevel Analytical Framework. *Journal of Industrial Ecology*, 21(1):6–15.



Indicator selection

MAIN CRITERIA

The indicator measures the quality and/or inequality of people's jobs.
The indicator gives useful insights in the quality and/or inequality of people's jobs without the need for real data.
The indicator can be used for measuring the quality and/or equality of the jobs of individuals.

selection method: Brieter et al., 2013	Indicator name Indicator source	Income distribution (ID) Azapagic & Perdan, 2000	# of high paying jobs Devenesc.	job distribution the author	quality of the working environment OECD, 2014	earnings quality OECD, 2014	Training Transdisciplinary Engineering book
	Scale of system				Society (regional) percentage of people with job strain and/or that are working very long hours incidence of job strain and/or working very long hours (60+H/week)		
	Dynamics						
	Conceptualisation						
	Scale of system			Society (regional) percentage of people working in the industries and/or biorefineries how many people are working at the farms/mills compared to how many people are working in the industries or biorefinery?			
	Dynamics						
	Conceptualisation						
	Scale of system	Organization The closer to unity this indicator is, the higher the level of social sustainability of the company.	Society (regional) Comparison of the mean vs. average wage			Group The higher, the better Earnings quality = average earnings * (1 - Inequality)	
	Dynamics	The ratio of the income of a CEO/board member and an average income in the company	Annual mean wage vs. average (in region)				
	Conceptualisation						Organization Total hours of employee training per year divided by the number of employees in that year Average number of hours of employee training per year

Phillips, P.S., Barnes, R., Bates, M.P., Coakeran,
T., 2006. A critical appraisal of an UK county
waste minimisation programme:
the requirement for regional facilitated
development of industrial symbiosis/ecology.

Resour. Conserv. Recycl. 46, 242&264.
Phillips, P.S., Barnes, R., Bates, M.P., Coakeran,
T., 2006. A critical appraisal of an UK county
waste minimisation programme:
the requirement for regional facilitated
development of industrial symbiosis/ecology.

Resour. Conserv. Recycl. 46, 242&264.
Azapagic, A., Perdan, S., 2000. Indicators of sustainable
development for industry. Process Saf. Environ. Prot. 78, 243&261.

Azapagic, A., Perdan, S., 2000. Indicators of sustainable
development for industry. Process Saf. Environ. Prot. 78, 243&261.
http://www.devenesc.com/sustain/indicators/2012_Sustainability_Progress_Report_Final.pdf
Transdisciplinary Engineering: Crossing Boundaries: Proceedings of the 23rd ...
<http://www.scienceirect.com/science/article/pii/S0195925605000521>
OECD Employment Outlook 2014

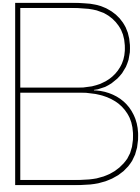
It measures new job created per annum by partnership.

Education and training: It measure the amount of employees trained per annum.
It shows an average distribution of wealth and could be expressed in term of income of the top 10% of employees per income of the bottom 10%.

Income distribution (ID)
OR: a ratio of the income of a CEO/board member and an average income in the company.
Work satisfaction (WS)
It represents the number of sick days or number of people "happy" with their job per employee.
Training
Annual mean wage vs. average (in region)
Employment potential
Average number of hours of employee training per year
high/low level

earnings quality
labour market security
quality of the working environment

Job quality

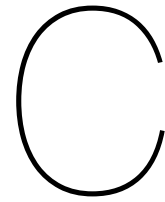


Assumptions

1. There are no **physical distances**; it is assumed that all agents live and work in a world where they are always able to travel to their jobs or requalification training.
2. **All the vacant jobs are known to all workers**, and they are able to apply for any job with a skill level required that is equal or lower than their own skill level.
3. **No worker agent death**; all the workers that are created stay in the model. They can be unemployed but still live in the system and perhaps find another job.
4. **No economics**; no internal calculations of money are simulated in the model. Decisions of workers are based on assumption 9, decisions of the union is based on complaints of the workers and they always try to reach their desired number of resources and demands, and decisions of the companies solely are based on filling their vacancies. Economics are not taken into account because this model tries to make a beginning of representing agents (the sugar industry workforce) socially and psychologically, while investigating the quality and skill level of their (potential future) jobs, and economics would expand the system too extensively for the time for this thesis.
5. There is an **abundance of workers** for the amount of jobs available; it is assumed that there will always be more workers than jobs, with enough abundance so that all of the jobs can be employed eventually.
6. The skill level of the workers determines the range of jobs they could have and it is possible for a company to not find any appropriate workers to fill all their jobs. The **penalty for having vacant jobs is a decline in productivity**, with productivity determined by the company's number of occupied jobs multiplied by the skill level required for those jobs, multiplied by the productivity weighing (100% productivity = total occupied jobs * skill level required * productivity weighing). The productivity weighing depends on the number of jobs that a company has: the total productivity can maximum be a 100%.
7. **All jobs are the same per company type**: a farm only has one type of job, a mill only has one type of job, a biorefinery only has one type of job, and an other industry only has one type of job. This simplification allows for the companies to increase or decrease the demands or resources of all of their jobs to the same level; this should simulate compliance with regulations like in the history of sugarcane plantations or mills.
8. Job quality is measured by the incidence of **job strain**, which is when there are more demands for a job then there are resources. Demands include time pressure and physical health risk factors, while resources include work autonomy and learning opportunities. There are three levels of demands and resources per different companies and thus different jobs: (0) no demands, (1) only time pressure, or (2) time pressure and physical health risk factors, and (0) no resources, (1) work autonomy, and (2) work autonomy and learning opportunities.

9. The action(s) that a worker performs fully depend on their perception of their own status and power, whether they have and who is their friend, how committed they are, how much they trust others, and if they experience job strain. The choices that they make when they have a certain perception, a certain friend, a certain level of commitment and trust, and perhaps job strain, are formalised by logical thinking, while keeping the system identification and decomposition in mind.
10. **Worker's opportunities**, i.e. whether they can apply for a job, apply for training, join the union, or strike, are determined by the level of status and power they perceive of themselves. These opportunities are actions that one takes whether they feel a status or power deficit: see the status-power theory of Kemper.
11. The **workers perception** of their own status and power is formalised as a number between -1 and 1, where workers feel a status or power deficit is when the level is below the threshold of adequate status or power, and they feel adequate status or power when the level is above that threshold. The feeling of having excessive status or power is not taken into account.
12. A worker's status is influenced by an increase or decrease in the number of resources and demands of their job, by an increase of their skill level, and when they are fired.
13. A worker's power is influenced when they are fired and hired.
14. The union will start **negotiating** with all the companies if more than 50% of all the workers have reported complaints.
15. The union can **negotiate** with each company individually, and they will first try to decrease the demands of the job of each company. The company will comply with a decrease of one demand level, if they have had at least one strike. The second negotiation, the union tries to increase the resources, this time the company will comply with the increase of one resources level when there have been 2 strikes at the company. The third time the goal of the negotiation is again a decrease of demands and the fourth time an increase in resources.
16. When a worker joins the union, the union becomes a "friend" of the worker.
17. When companies are supplied with hiring subsidies, they can hire workers that are unemployed, even when they are not skilled enough for the job.
18. Requalification subsidies are used to provide general skills training for the workers of the farms and mills. Workers can always apply for these trainings and are able to have training while they have a job. The number of training positions is determined by a chosen percentage of the total number of jobs in the farms and mills. It is assumed that all workers that have training gain the skill level that the training has; i.e. all workers successfully finish the training within one year.
19. Requalification programs are only available when the union is subsidized with requalification subsidies.
20. Companies always want to fill their vacancies, it does not matter to them what status, power, trust or commitment level a worker who is applying has.
21. **Workers are hired** by the companies on a **first-come first-serve basis**.
22. Workers only want to join a strike when they experience job strain.
23. There is a low and high level, or threshold, of the workers characteristics: this can be determined per simulation run.
24. To simulate a more random going in and out of business of the companies, the following dynamic is used for the dynamic company scenario. From 2013 on, every year, a number is randomly picked from a list, which stands for the number of companies (except mills) that go bankrupt in that year: [0 0 1 1 2 2 3 4]. Also from 2013 on, every year a number is randomly picked from a list, which stands for the number of other industries that are founded in that year: [0 0 0 0 1 1 2 3]. Finally, a number is randomly picked from a list, which stands for the number of biorefineries that are founded in that year: [0 0 0 0 1 1 1 2].

25. Companies that go bankrupt, die in the model. This means that all workers are fired.
26. A company that is founded after 2013 starts with the same state as the companies of the same type initially created in the model.



Software data structures

Workers have:

- skills: float ≥ 0.01 and ≤ 1 .
- status: float ≥ -1 and ≤ 1 .
- power: float ≥ -1 and ≤ 1 .
- commitment: float ≥ 0 and ≤ 1 .
- trust-of-others: float ≥ 0 and ≤ 1 .
- company-friend?: boolean.
- union-friend?: boolean.
- join-strike?: boolean.
- opportunities: a list.
- demands-last: integer ≥ 0 and ≤ 2 .
- resources-last: integer ≥ 0 and ≤ 2 .
- demands-now: integer ≥ 0 and ≤ 2 .
- resources-now: integer ≥ 0 and ≤ 2 .
- skills-last: float ≥ 0.01 and ≤ 1 .
- number: integer.
- fired?: boolean.
- hired?: boolean.
- apply-training: boolean.
- job: object.
- training: object.

Companies have:

- technology: string.
- strikes: integer.

- vacancies: integer.
- bankrupt?: boolean.
- operating?: boolean.
- jobs: objects.

The union has:

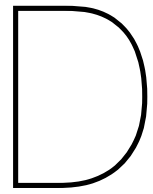
- current-resources: integer ≥ 0 and ≤ 2 .
- current-demands: integer ≥ 0 and ≤ 2 .
- desired-resources: integer ≥ 0 and ≤ 2 .
- desired-demands: integer ≥ 0 and ≤ 2 .
- complaints: integer.
- negotiation: integer.
- trainings: integer.
- training: objects.

Jobs have:

- skills-required: float ≥ 0.01 and ≤ 1 .
- resources: float ≥ 0.01 and ≤ 1 .
- demands: float ≥ 0.01 and ≤ 1 .
- employee: integer.
- applicant?: integer.

Training has:

- trainee: integer.
- skill-added: float.



States and actions of agents and objects

Agents

Workers
states
<i>skills</i> [float] <i>status</i> [float] <i>power</i> [float] <i>commitment</i> [float] <i>trust-of-others</i> [float] <i>company-friend?</i> [boolean] <i>union-friend?</i> [boolean] <i>join-strike?</i> [boolean] <i>opportunities</i> [list] <i>demands-last</i> [integer] <i>resources-last</i> [integer] <i>demands-now</i> [integer] <i>resources-now</i> [integer] <i>skills-last</i> [float] <i>number</i> [integer] <i>fired?</i> [boolean] <i>hired?</i> [boolean] <i>apply-training</i> [boolean] <i>job</i> [object] <i>training</i> [object]
actions
perceive make-decision update-perceptions update-memory apply report

Companies
states
<i>technology</i> [string] <i>strikes</i> [integer] <i>productivity</i> [integer] <i>vacancies</i> [integer] <i>bankrupt?</i> [boolean] <i>operating?</i> [boolean] <i>jobs</i> [object]
actions
hire fire

Union
states
<i>current-resources</i> [integer] <i>current-demands</i> [integer] <i>desired-resources</i> [integer] <i>desired-demands</i> [integer] <i>complaints</i> [integer] <i>negotiation</i> [integer] <i>trainings</i> [integer] <i>training</i> [object]
actions
requalify-workers negotiate

Objects

Jobs
states
<i>skills-required</i> [float] <i>resources</i> [integer] <i>demands</i> [integer] <i>employee</i> [integer] <i>applicant?</i> [number of agent]

Training
states
<i>trainee</i> [number of agent] <i>skill-added</i> [float]

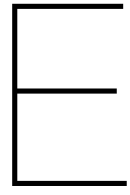
Scenario

Initial setup
Per company: <i>technology</i> [string] <i>#-of-jobs</i> [integer]

Scenario
states
<i>hiring-subsidies</i> [float] <i>requalification-subsidies</i> [float] <i>commitment</i> [float] <i>trust-of-others</i> [float]

Output
<i>%unemployed</i> [integer] <i>%vacancies</i> [integer] <i>%job-strain</i> [integer] <i>average-skill-level</i> [integer] <i>%status-deficit</i> [integer] <i>%status-adequate</i> [integer] <i>average-power</i> [float] <i>average-status</i> [float]

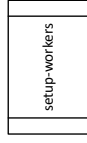
Global variables
<i>total-workers-per-company</i> [integer] <i>total-workers</i> [integer] <i>total-jobs</i> [integer] <i>total-jobs-per-company</i> [integer] <i>farms-mills-jobs</i> [integer] <i>total-skills</i> [float]



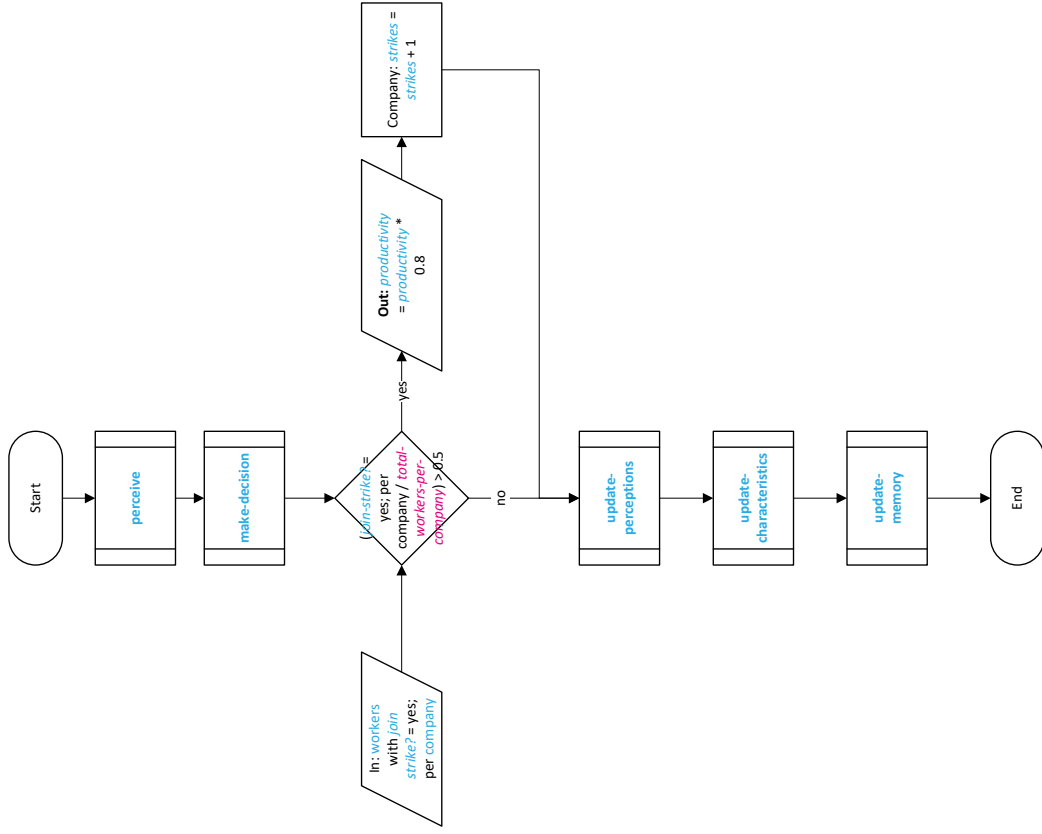
Flowcharts

Worker

Flowchart 1: setup-workers

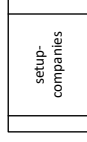


Flowchart 3: Worker actions per tick

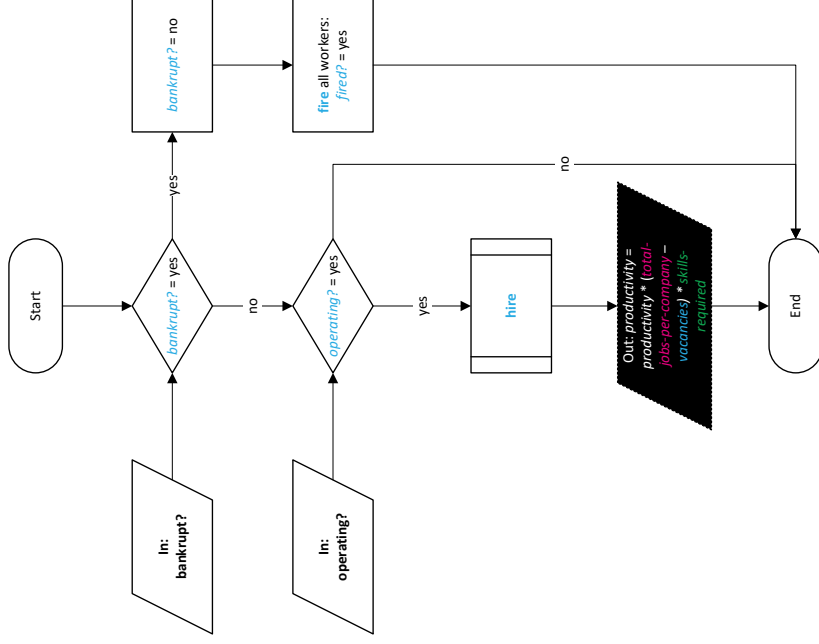


Company

Flowchart 2: setup-companies

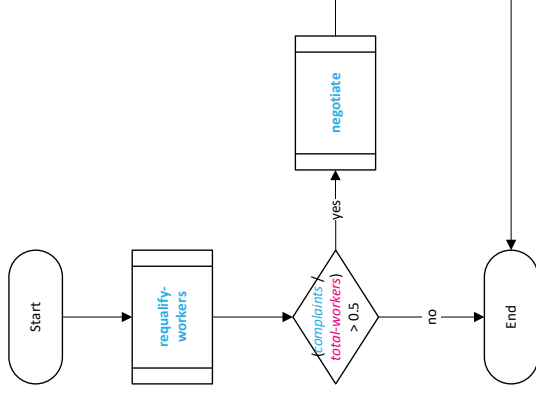


Flowchart 4: Company actions per tick



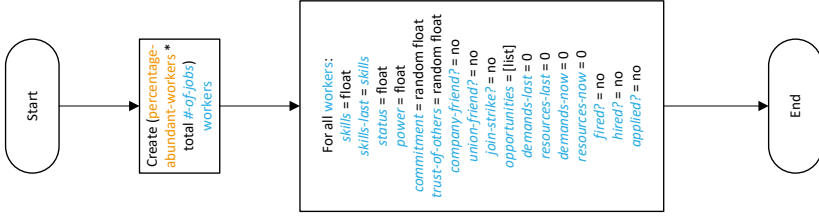
Union

Flowchart 5: Union actions per tick



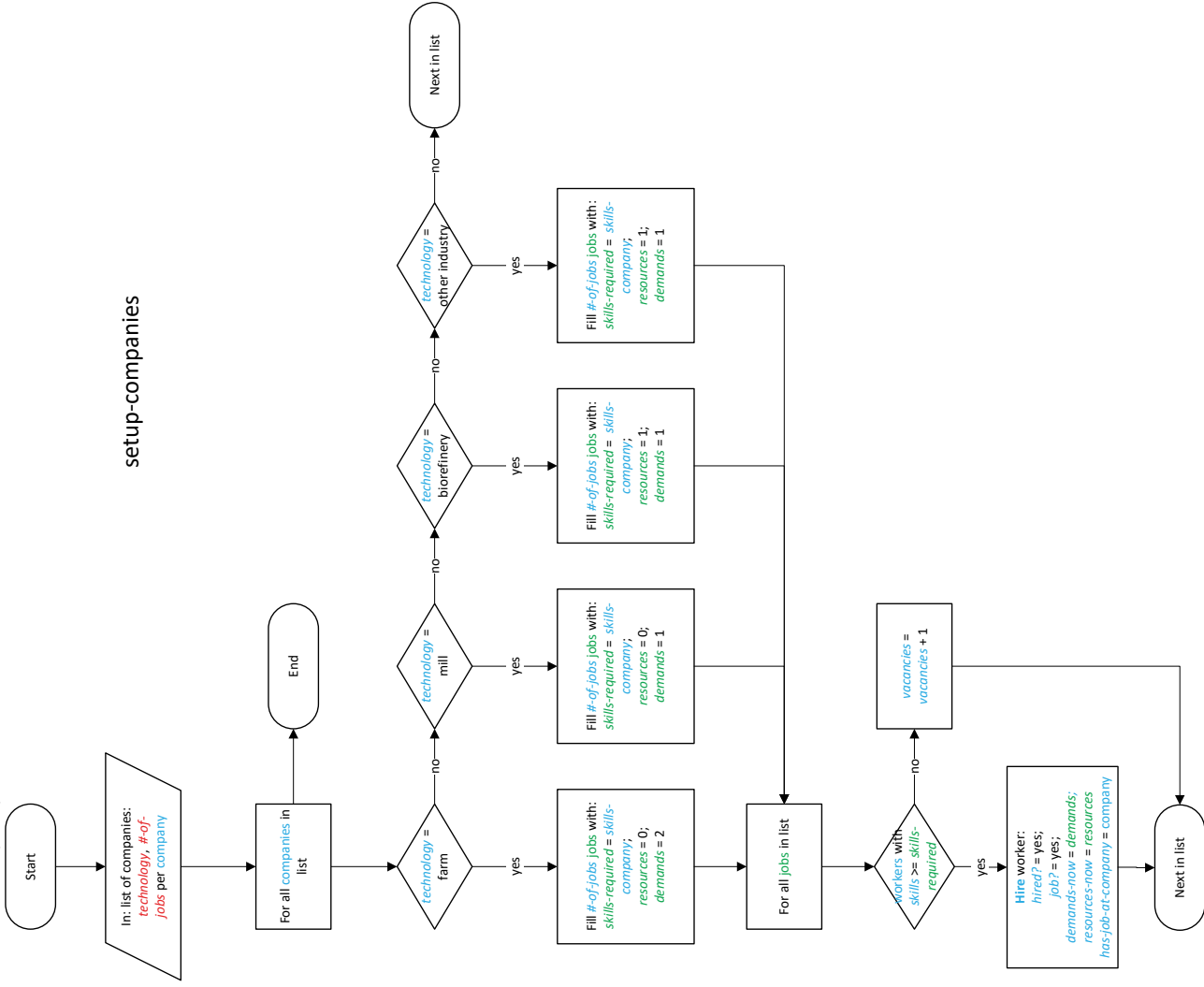
setup-workers

Flowchart 6: setup-workers



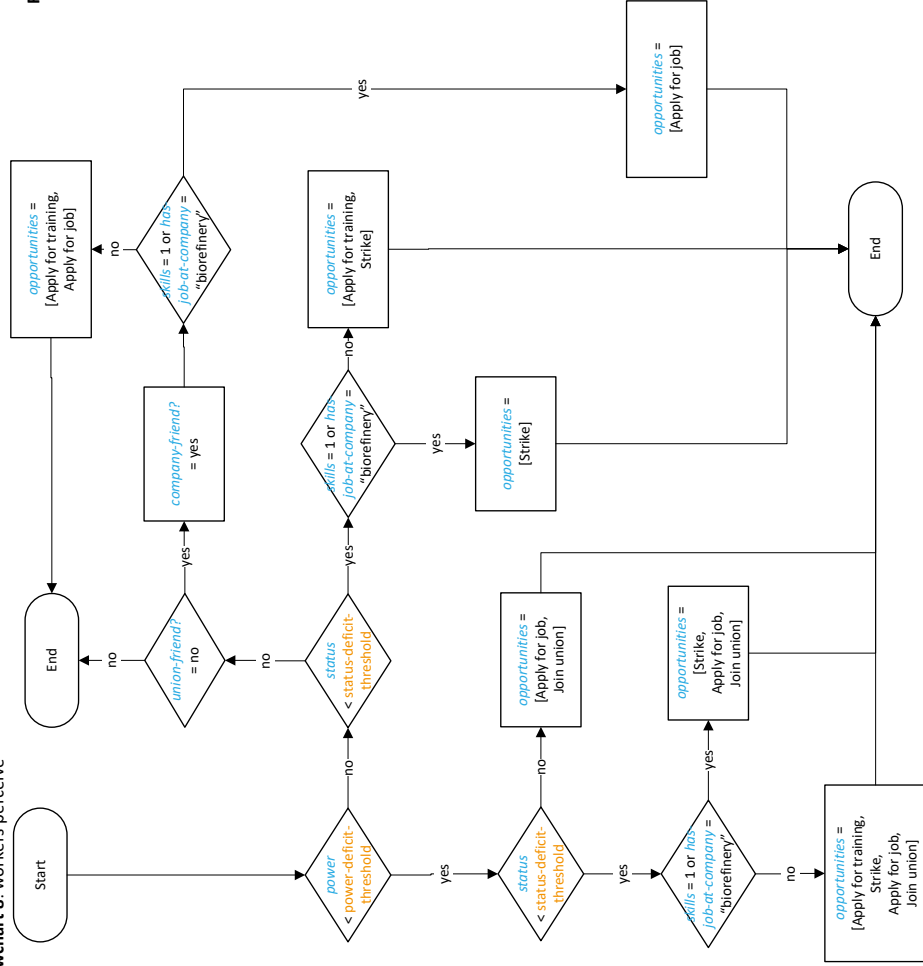
Flowchart 7: setup-companies

setup-companies



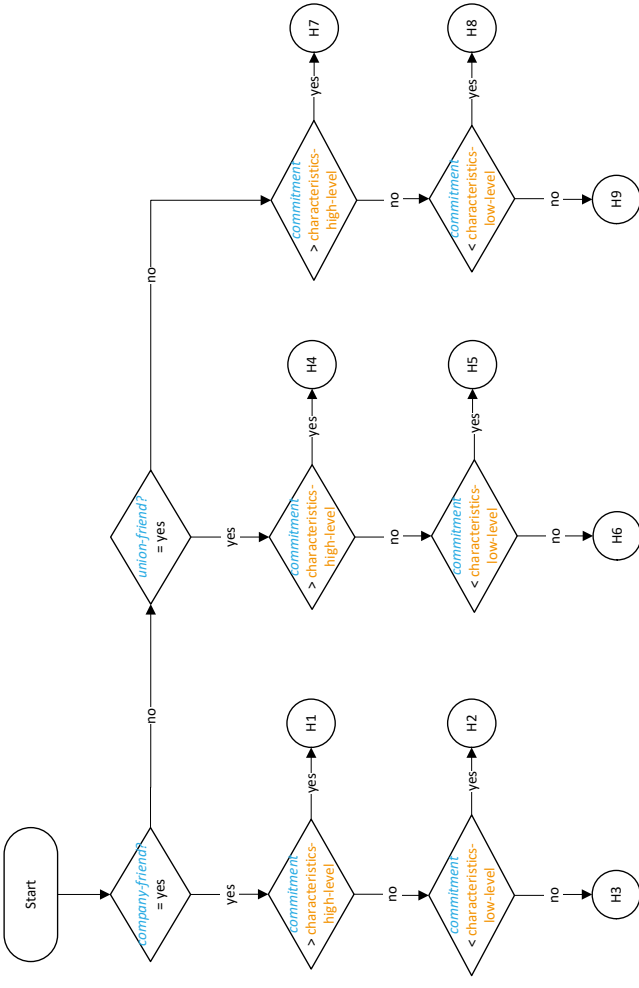
perceive

Flowchart 8: workers perceive



make-decision

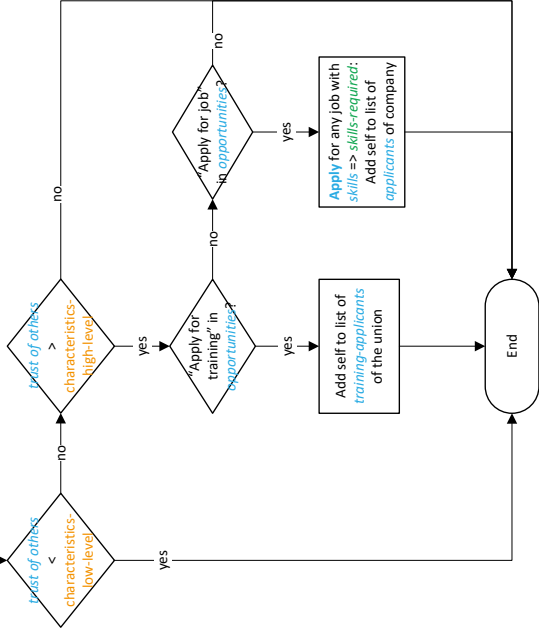
Flowchart 9: workers make decisions



heuristics

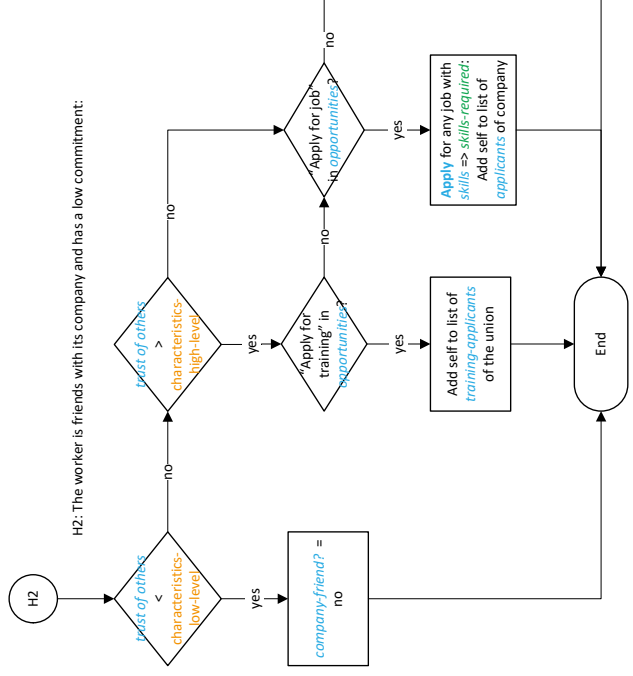
Flowchart 10: workers heuristic 1

H1: The worker is friends with its company and has a high commitment



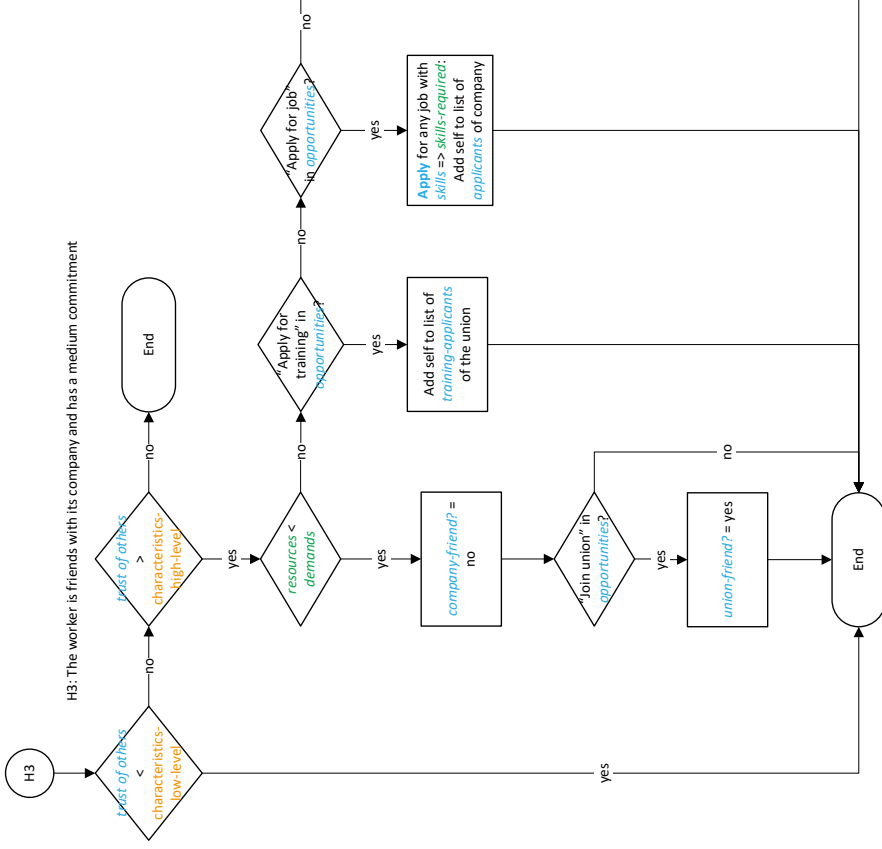
Flowchart 11: workers heuristic 2

H2: The worker is friends with its company and has a low commitment:



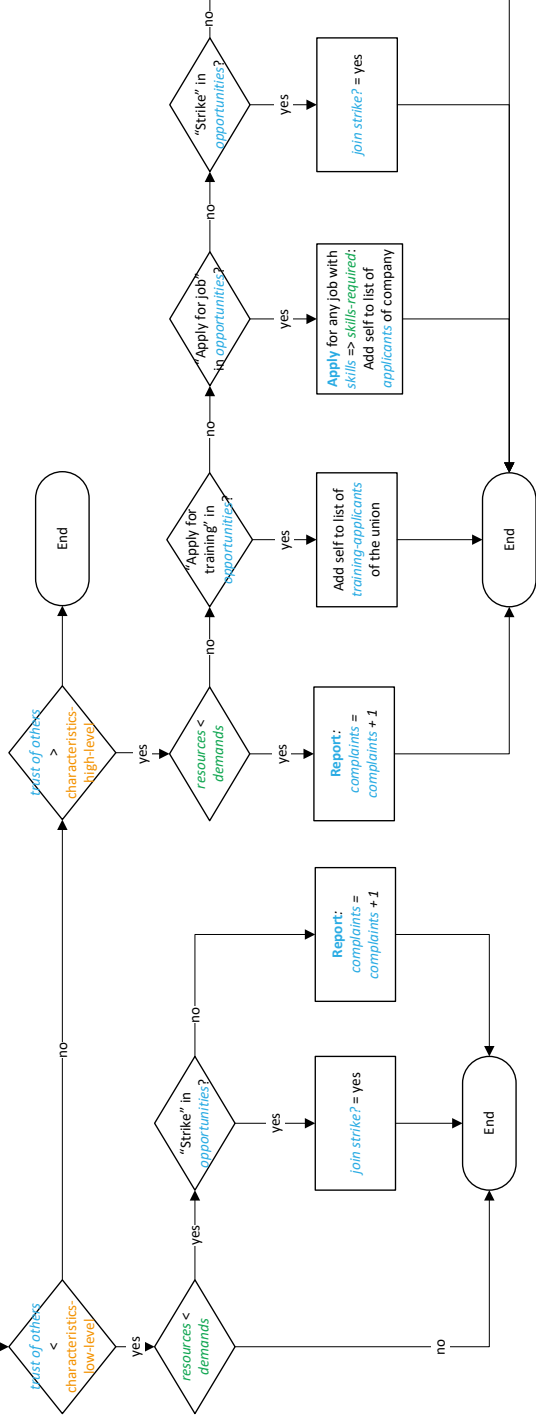
Flowchart 12: workers heuristic 3

H3: The worker is friends with its company and has a medium commitment



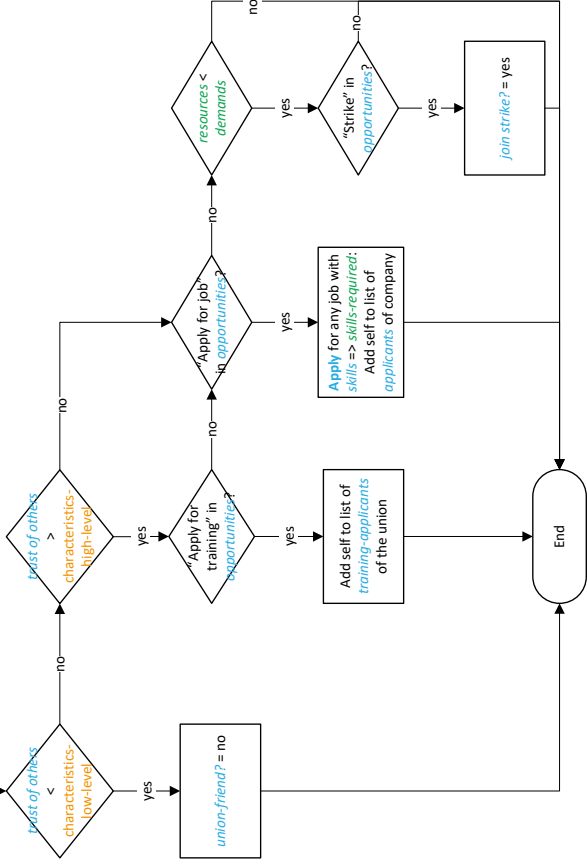
Flowchart 13: workers heuristic 4

H4: The worker is friends with the union and has a high commitment



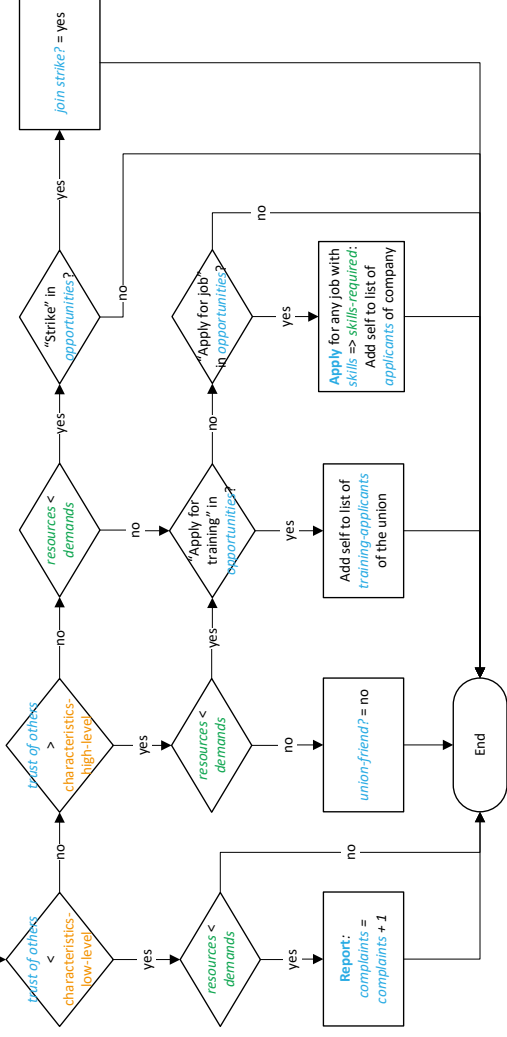
Flowchart 14: workers heuristic 5

H5: The worker is friends with the union and has a low commitment



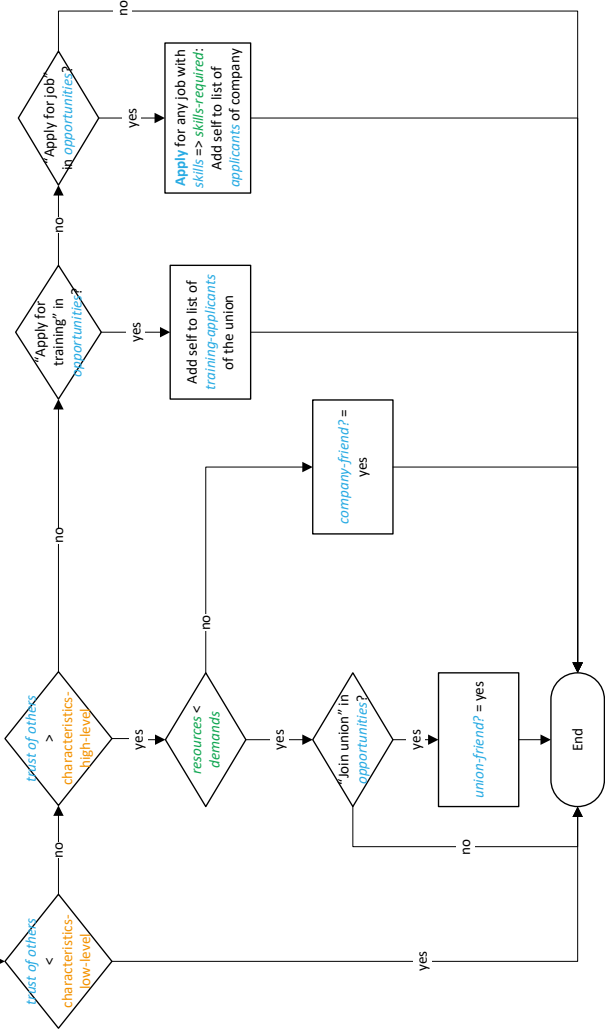
Flowchart 15: workers heuristic 6

H6: The worker is friends with the union and has a medium commitment



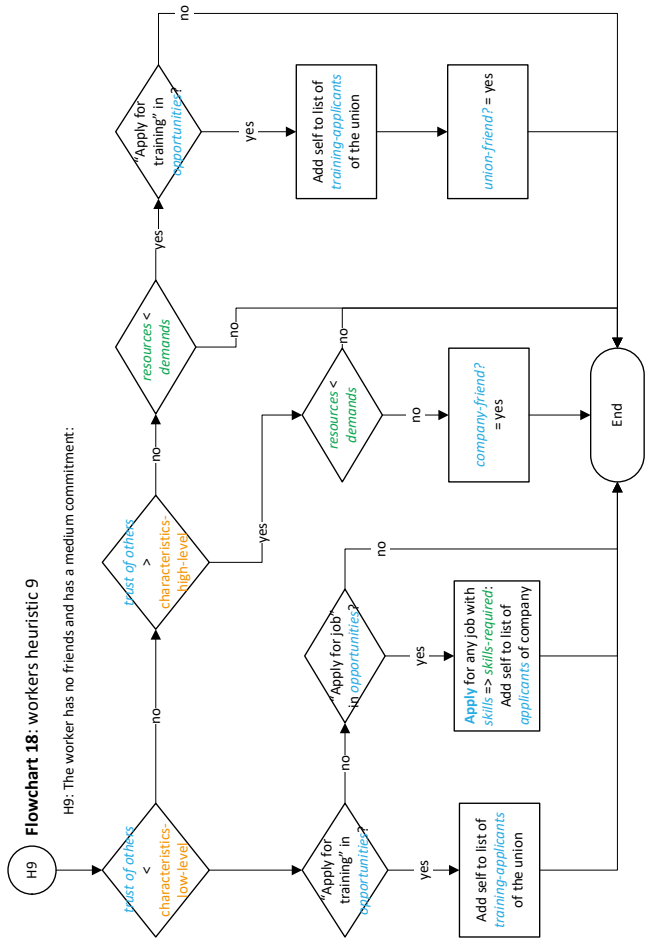
Flowchart 16: workers heuristic 7

H7: The worker has no friends and has a high commitment



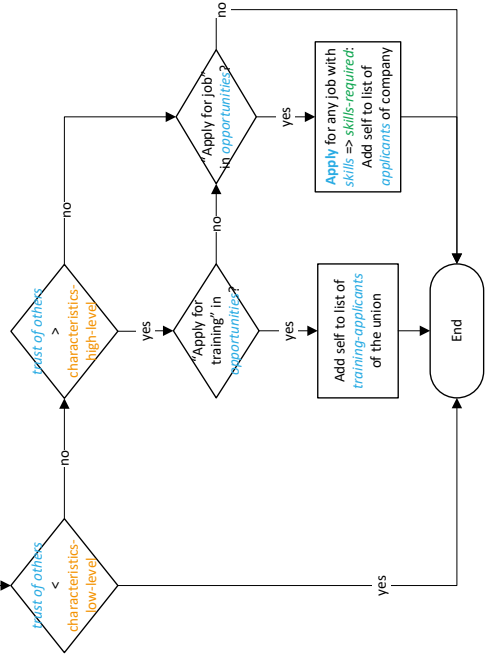
Flowchart 18: workers heuristic 9

H9: The worker has no friends and has a medium commitment:

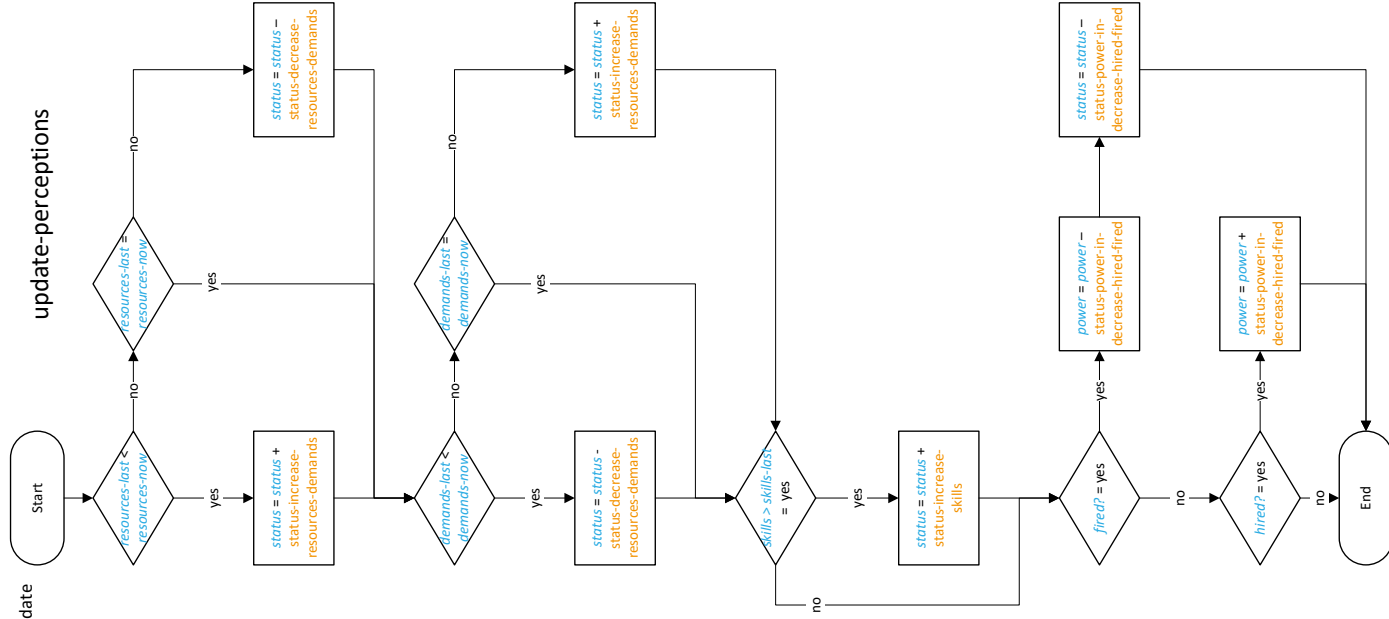


Flowchart 17: workers heuristic 8

H8: The worker has no friends and has a low commitment



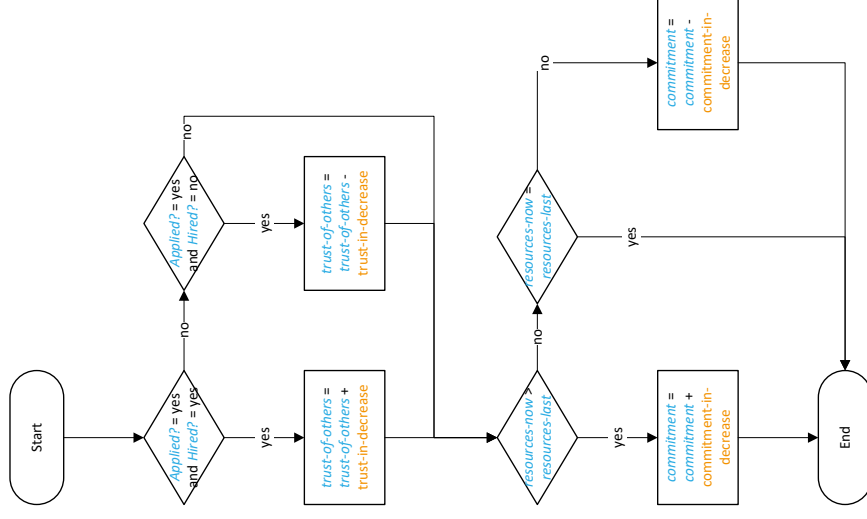
Flowchart 19: workers update perceptions



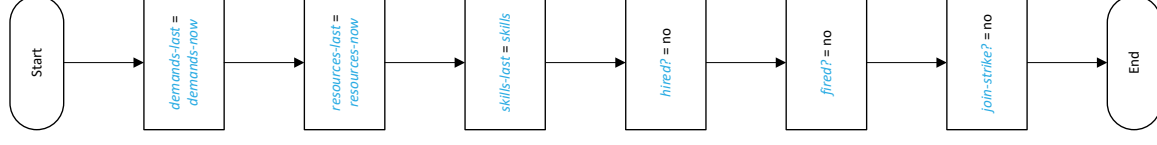
update-perceptions

update-characteristics

Flowchart 20: workers update characteristics



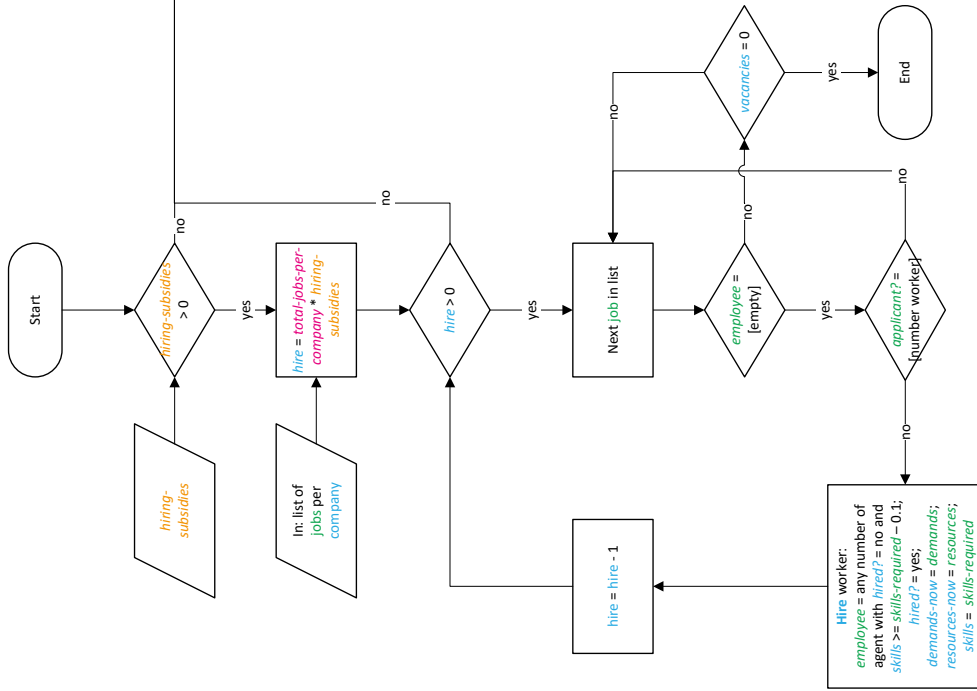
Flowchart 21: workers update memory



update-memory

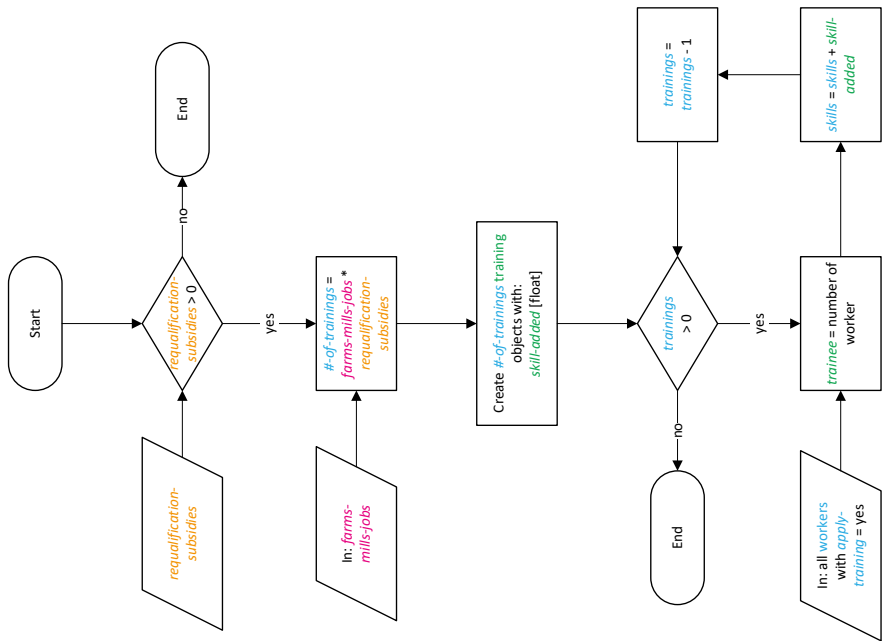
hire

Flowchart 22: companies hire



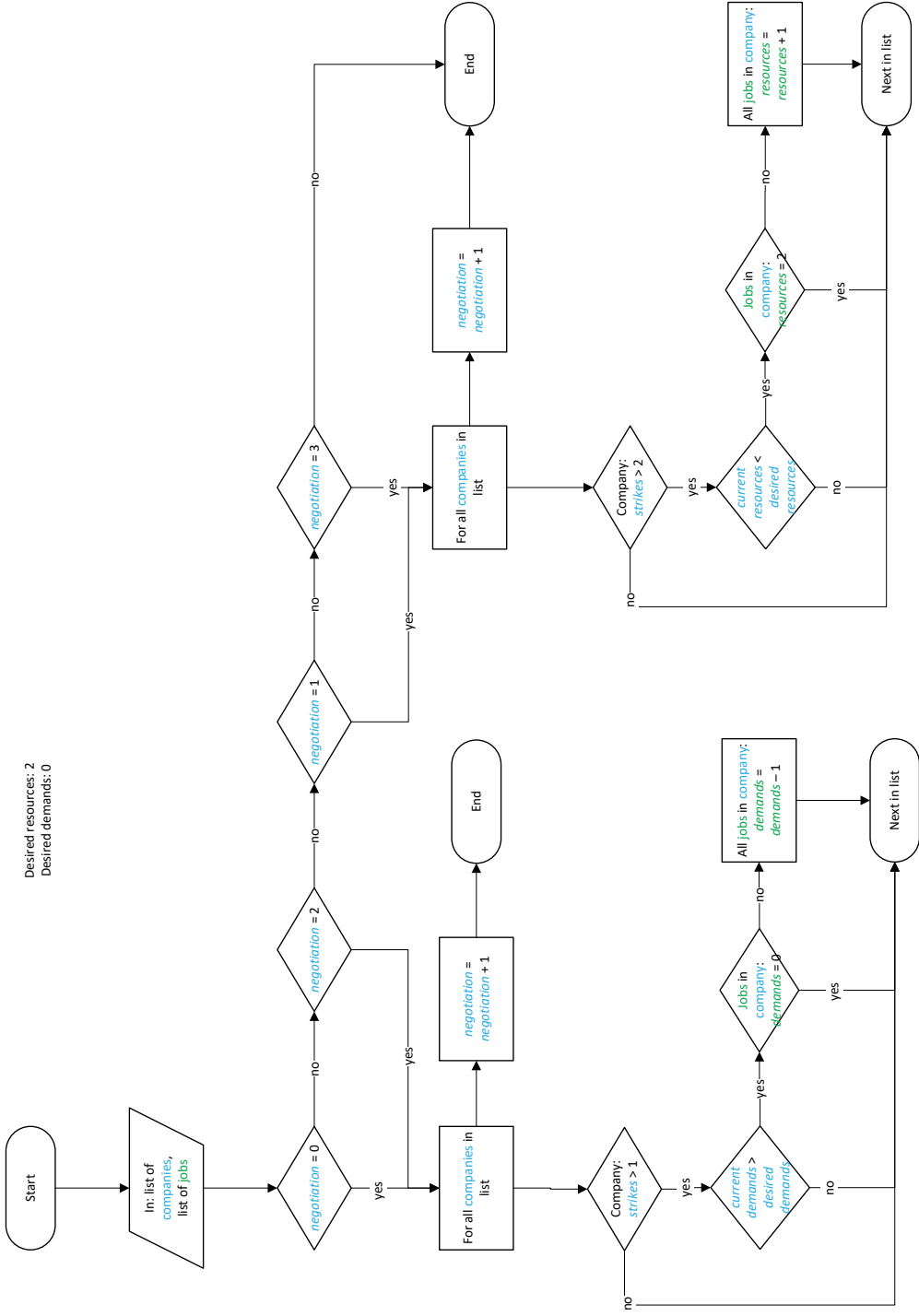
requally-workers

Flowchart 23: unions requally workers

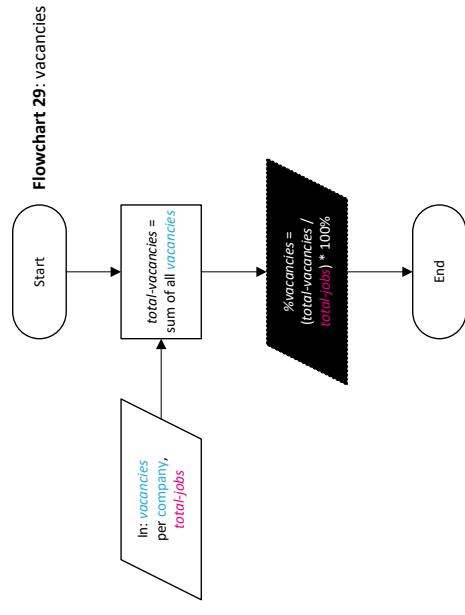
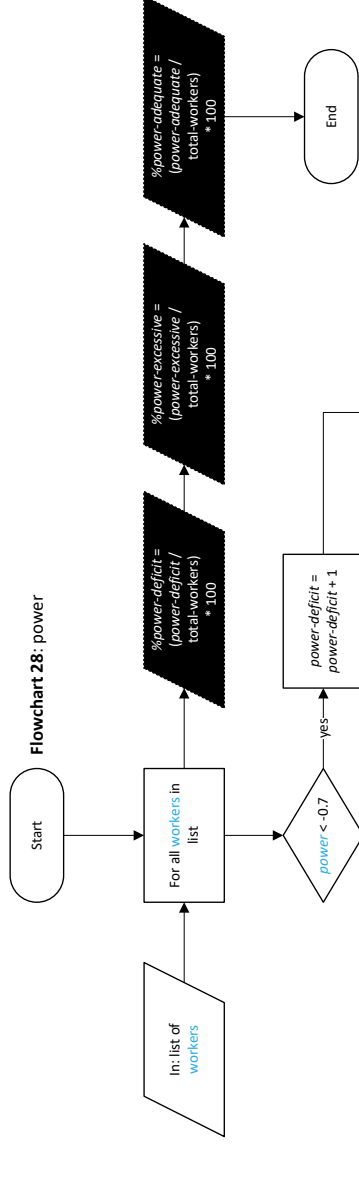
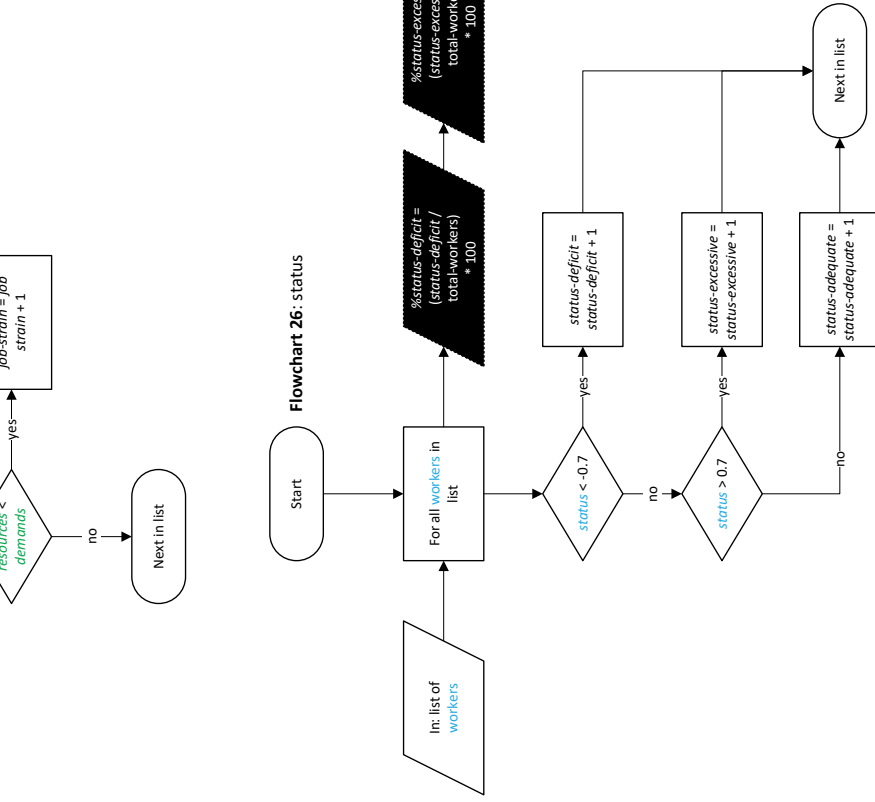
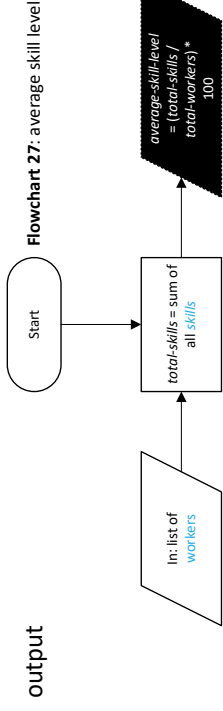
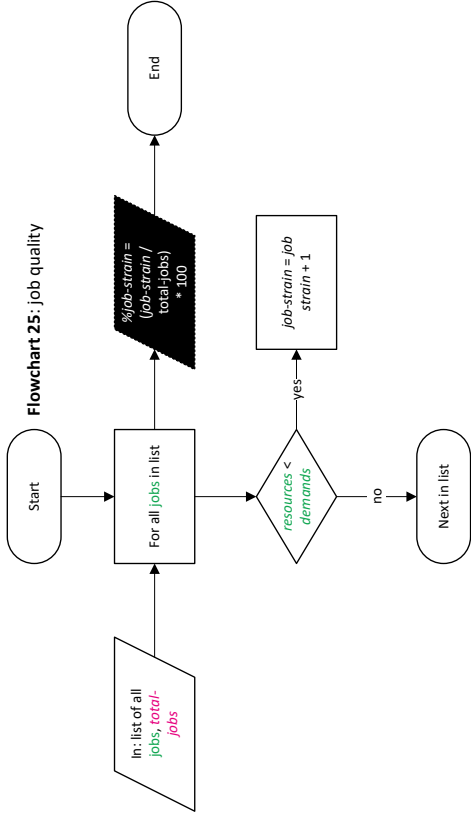


negotiate

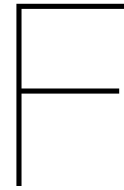
Flowchart 24: unions negotiate



Desired resources: 2
Desired demands: 0



output



Historical data

The data for the (combined) model for the following inputs is taken from these sources:

- The amount of sugarcane processed in 2000: Peixoto (2005). This determines the number of jobs per mill.
- The amount of sugarcane processed in the years 2006-2015: SISERJ (2016). This determines the number of jobs per mill.
- The area of the sugarcane crops of the farms: CONAB (2015). This determines the number of farms.
- The number of mills in the years 1996-2009: Castro (2009).
- The number of mills in the years 2001-2002, 2007-2010: Ribeiro (2010).
- The number of mills in 2013: Ruimax Viana Soares and Alcimar das Chagas Ribeiro (2013).
- The ethanol and sugar price in the years 1999-2007: Economia Agricola UFRRJ (2017).
- The sugar price in the years 2001-2017: CEPEA (2017).
- The ethanol price in the years 2002-2017: CEPEA.



Experiments

Semi-random company dynamics

- After 2013, every year a X number of companies go bankrupt and fire all of their employees. X is randomly picked from the following list: [0 0 1 1 2 2 3 4]; there is a 25% chance of 0, 1 or 2 companies going bankrupt and a 12.5% chance of 3 or 4 companies going bankrupt.
- After 2013, every year a Y number of other industries are founded and try to hire sufficient employees. Y is randomly picked from the following list: [0 0 0 0 1 1 2 3]; there is a 50% chance of 0 other industries being founded, a 25% chance of 1 other industry being founded and a 12.5% chance of 2 or 3 other industries being founded.
- After 2013, every year a Z number of biorefineries are founded and try to hire sufficient employees. Z is randomly picked from the following list: [0 0 0 0 1 1 1 2]; there is a 50% chance of 0 biorefineries being founded, a 37.5% chance of 1 biorefinery being founded and a 12.5% chance of 2 biorefineries being founded.

Table G.1: Parameter values of the standard current and proposed scenario

Inputs	Value current	Value proposed
<i>Abundant workers %</i>	1.4	1.4
<i>Initial union members %</i>	37	37
<i>Input other industries</i>	10	10
<i>Biorefineries input in 2013</i>	0	20
<i>Initial power and status deficit</i>	TRUE	TRUE
<i>Requalification subsidies</i>	0	25
<i>Hiring subsidies</i>	0	25
<i>Random company bankrupt</i>	TRUE	TRUE
Thresholds	Value	
<i>Power insufficient at</i>	-0.3	
<i>Status insufficient at</i>	-0.3	
<i>Characteristics high level</i>	0.7	
<i>Characteristics low level</i>	0.3	
<i>Commitment de- and increase</i>	0.1	
<i>Trust de- and increase</i>	0.1	
<i>Status increase for skills</i>	0.05	
<i>Power and status de- and increase when hired or fired</i>	0.1	
<i>Status decrease for lack of resources and demands</i>	0.1	
<i>Status increase for sufficient resources and demands</i>	0.1	

EXPERIMENTS PERFORMED

Standard scenarios - all with 200% the number of workers over initial jobs

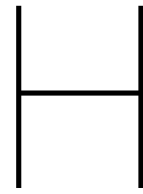
- Standard current scenario over time, static company scenario, 50 repetitions
- Standard current scenario over time with a random company bankrupt every year, static company scenario, 50 repetitions
- Standard proposed scenario over time, static company scenario, 50 repetitions
- Standard proposed scenario over time with a random company bankrupt every year, static company scenario, 50 repetitions
- Proposed dynamic company scenario over time, 50 repetitions

Exploration scenarios - for the exploration of the scenario space

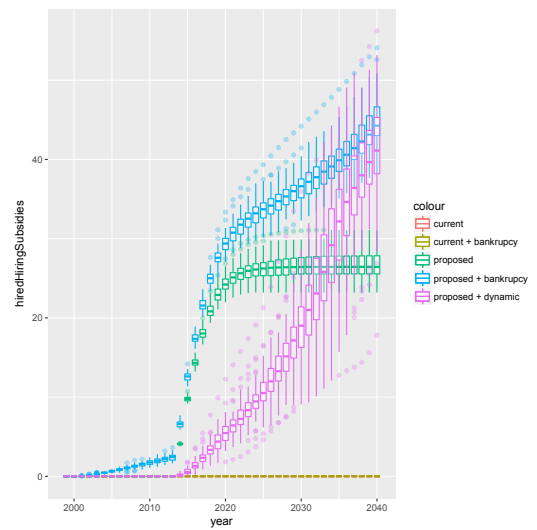
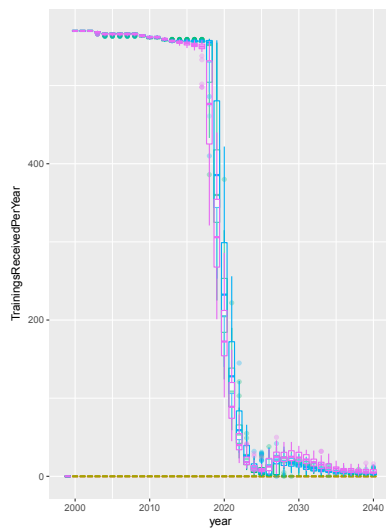
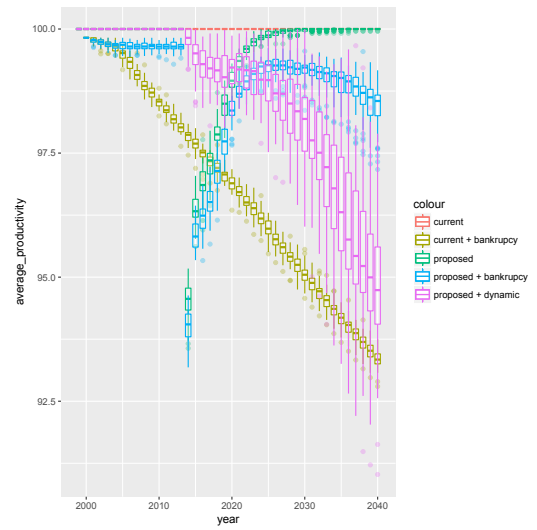
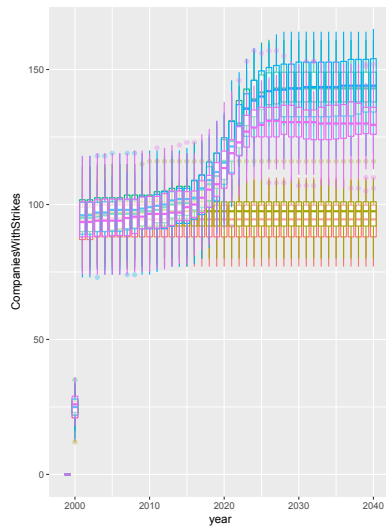
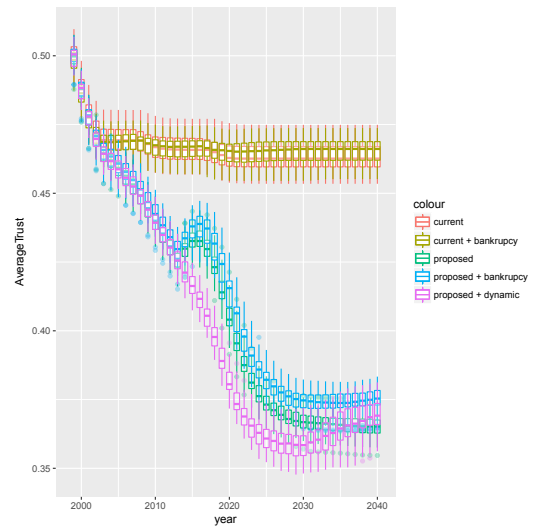
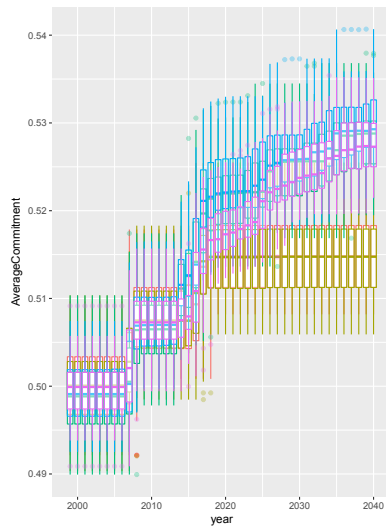
- Proposed scenario with 100 to 200% the number of workers compared with the initial number of jobs at a 100%, with steps of 10%, static company scenario, 50 repetitions
- Proposed scenario with 20 to 200% the number of workers compared with the initial number of jobs at a 100%, with steps of 20%, dynamic company scenario, 10 repetitions
- Proposed scenario with different types of subsidies:
 - Both subsidies always on with different levels of height (0, 10, 25, 50, 75, 100), static company scenario, full factorial, 10 repetitions per setting
 - Both subsidies always on with different levels of height (0, 2, 4, 6, 8, 10), dynamic company scenario, full factorial, 10 repetitions per setting
 - Four years on / four years off for both subsidies in phase, 50 repetitions
 - Four years on / four years off for both subsidies out of phase, 50 repetitions
 - Exponential increase of both subsidies, 50 repetitions
 - Exponential decrease of both subsidies, 50 repetitions
 - Randomly distributed subsidies over 20% of the time, 50 repetitions
 - Random height of the subsidies every year, 50 repetitions
- Full factorial thresholds experiments, see Table G.2, 50 repetitions per experiment

Table G.2: Exploratory threshold and increment experiments for the proposed dynamic company scenario

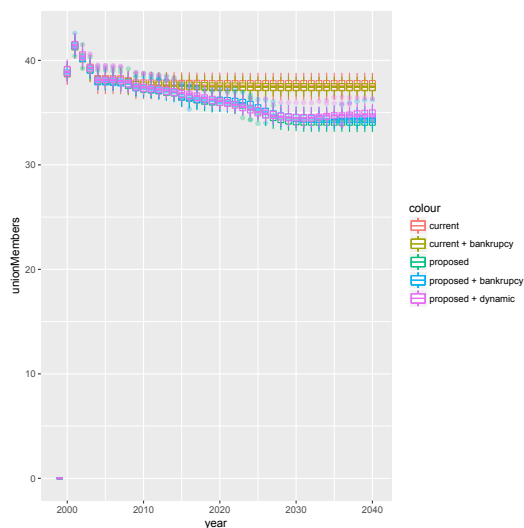
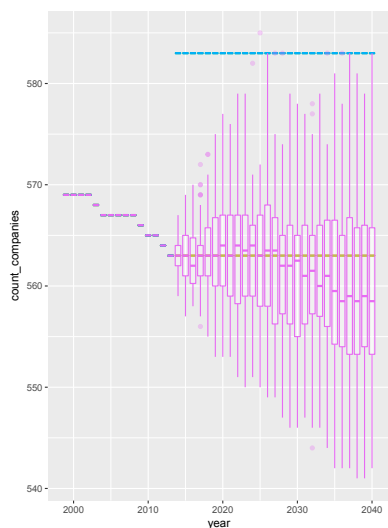
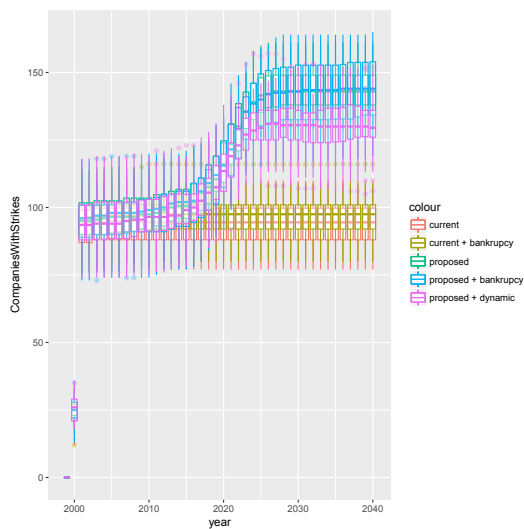
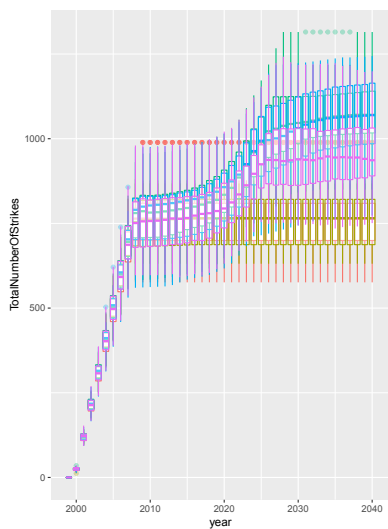
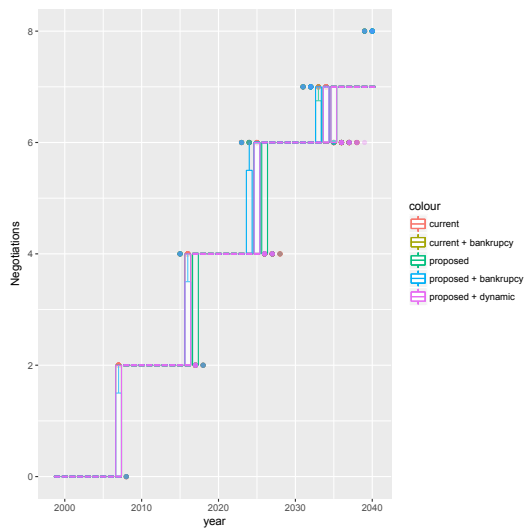
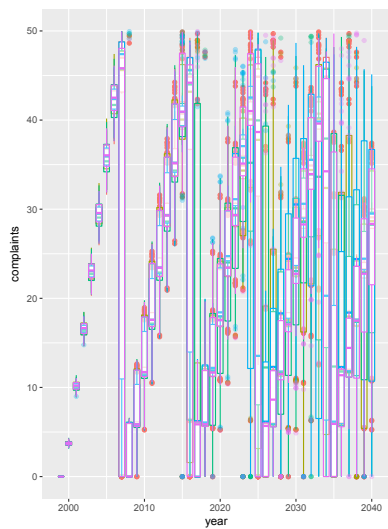
Thresholds and increment experiments	Exp. 1: characteristics thresholds	Exp. 2: characteristics increments	Exp. 3: power and status thresholds	Exp. 4: power and status in- crements
<i>Power insufficient at</i>	-0.3	-0.3	-0.3, 0, 0.3	-0.3
<i>Status insufficient at</i>	-0.3	-0.3	-0.3, 0, 0.3	-0.3
<i>Characteristics high level</i>	0.7, 0.8, 0.9	0.7	0.7	0.7
<i>Characteristics low level</i>	0.1, 0.2, 0.3	0.3	0.3	0.3
<i>Commitment de- and increase</i>	0.1	0.05, 0.1, 0.2	0.1	0.1
<i>Trust de- and increase</i>	0.1	0.05, 0.1, 0.2	0.1	0.1
<i>Status increase for skills</i>	0.05	0.05	0.05	0.05, 0.1, 0.2
<i>Power and status de- and increase when hired or fired</i>	0.1	0.1	0.1	0.05, 0.1, 0.2
<i>Status decrease for lack of re- sources and demands</i>	0.1	0.1	0.1	0.05, 0.1, 0.2
<i>Status increase for sufficient re- sources and demands</i>	0.1	0.1	0.1	0.05, 0.1, 0.2



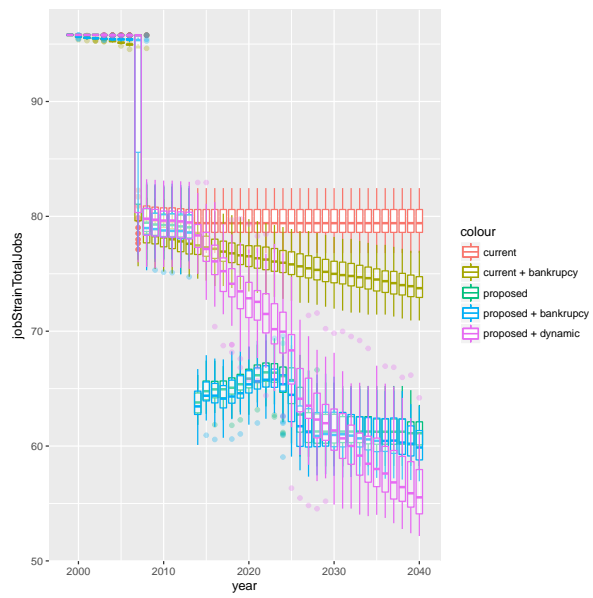
Current and proposed scenarios



Results of the scenario explorations.

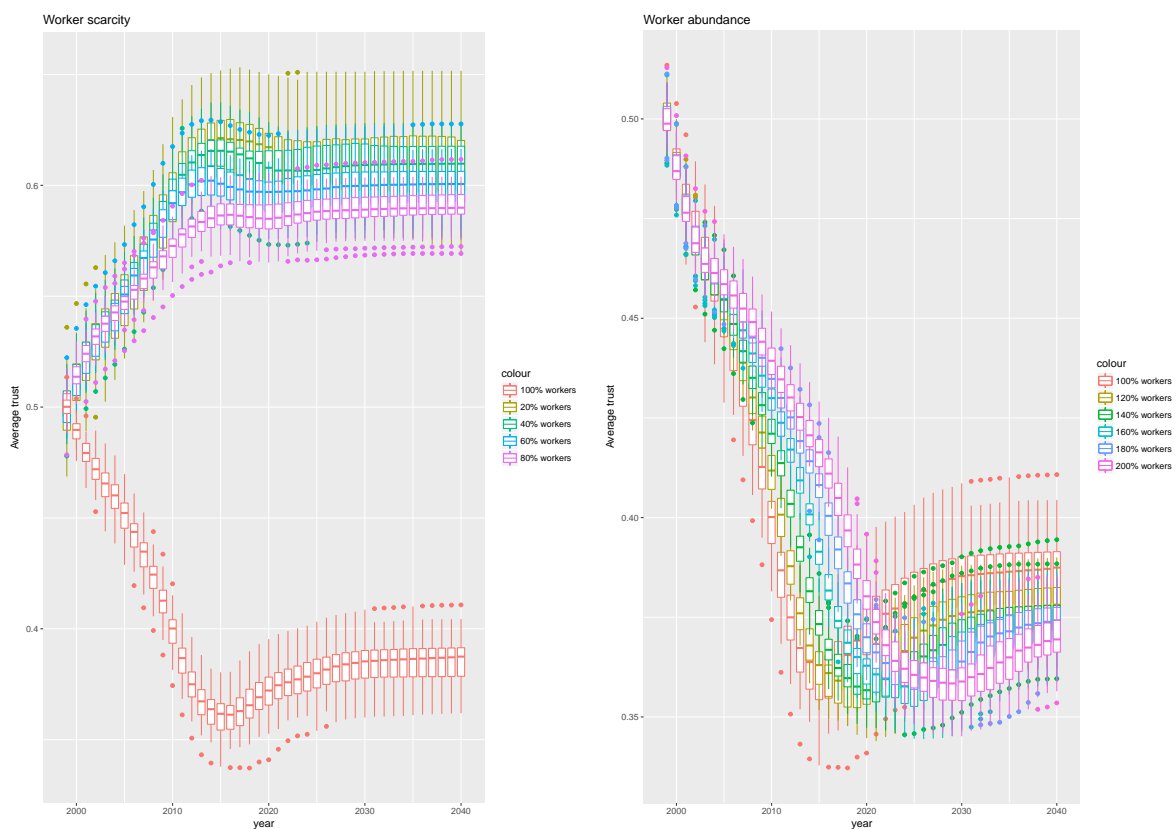


More results of the scenario explorations.



Percentage jobs with job strain of all the jobs of all the companies.

Scarcity and abundance of workers

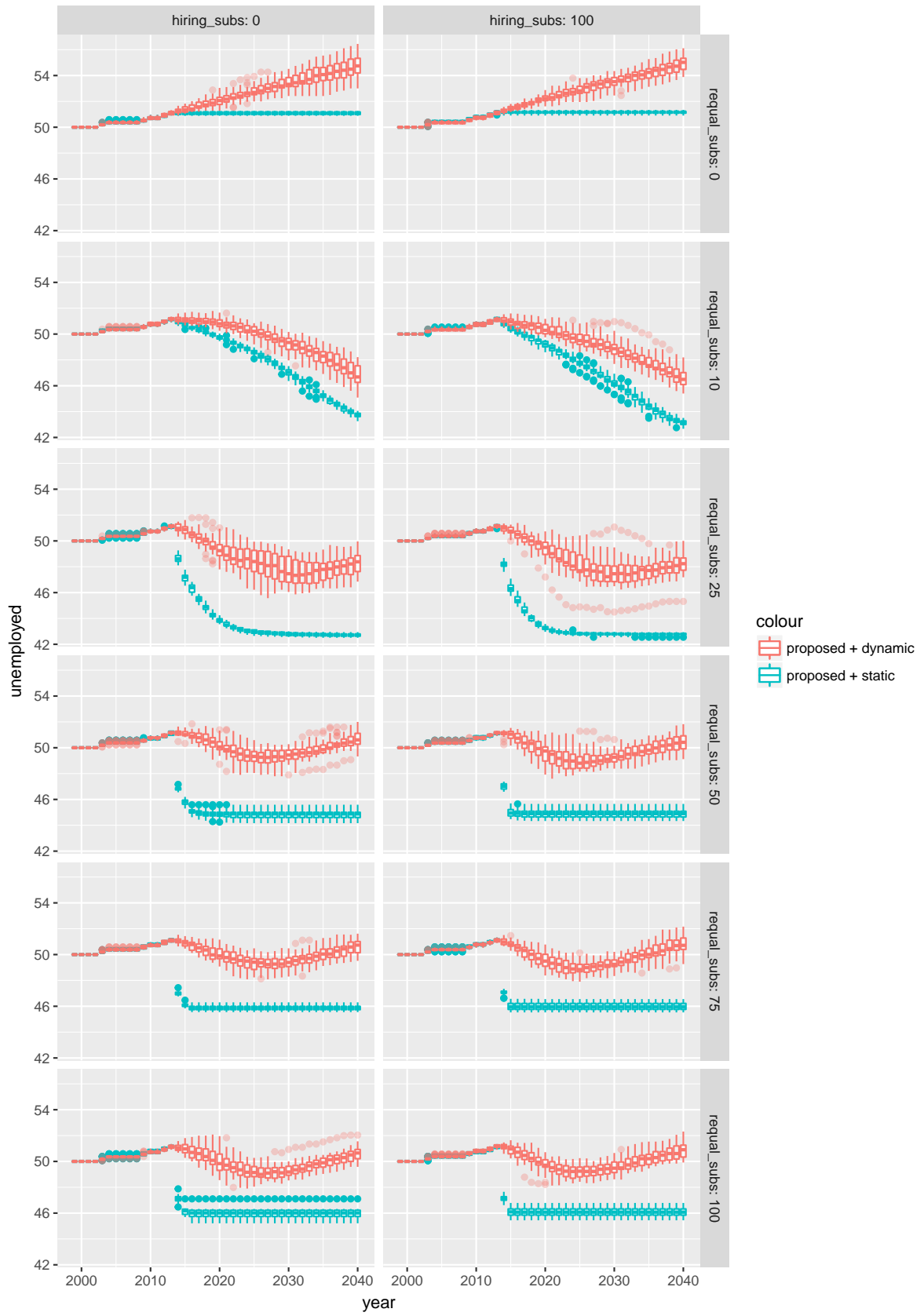


(a) The average trust of the workers over time with a different percentage of a scarcity of workers. (b) The average trust of the workers over time with different percentage of an abundance of workers.

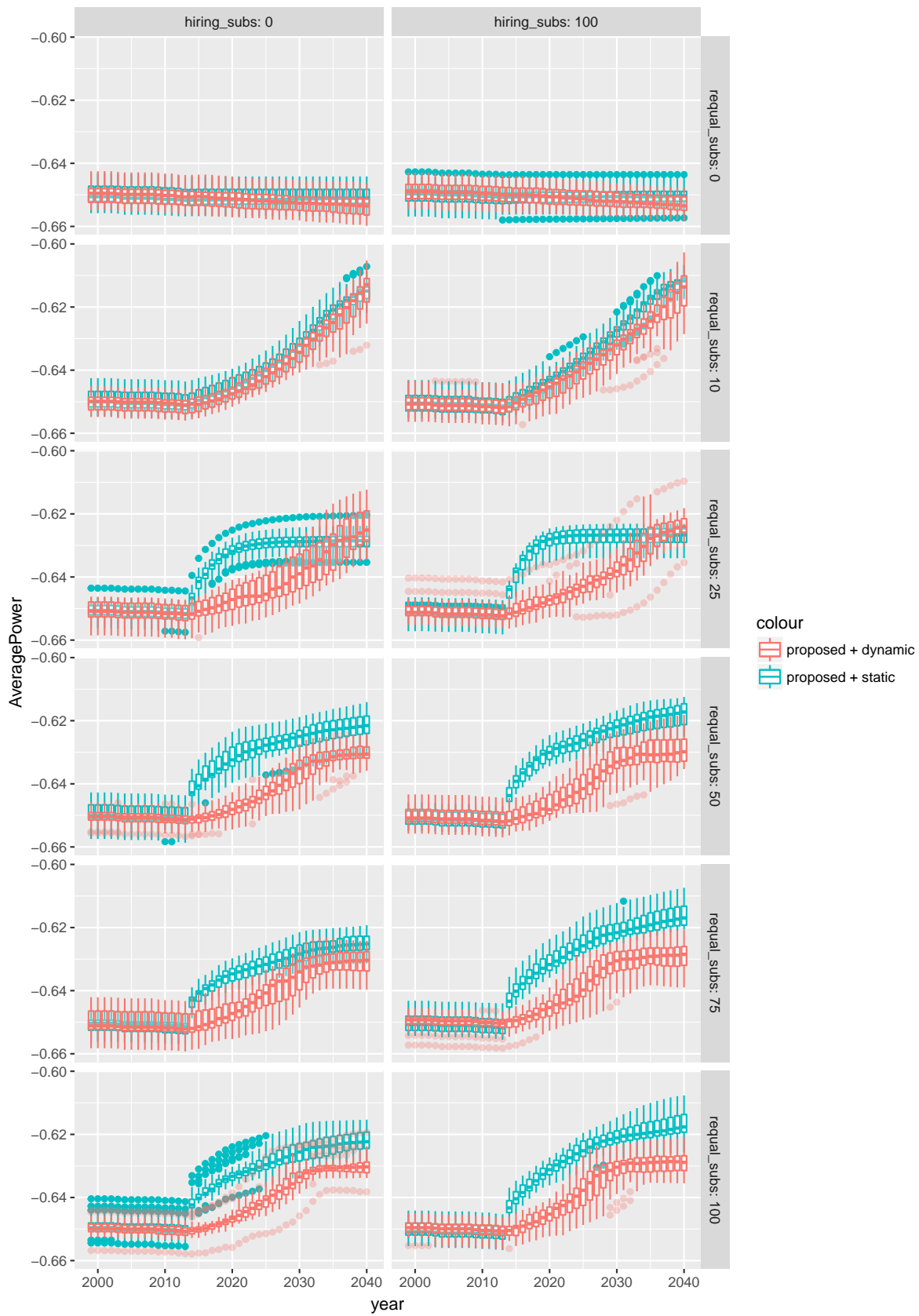
Average trust of the workers in the case of a scarcity or abundance of workers.

J

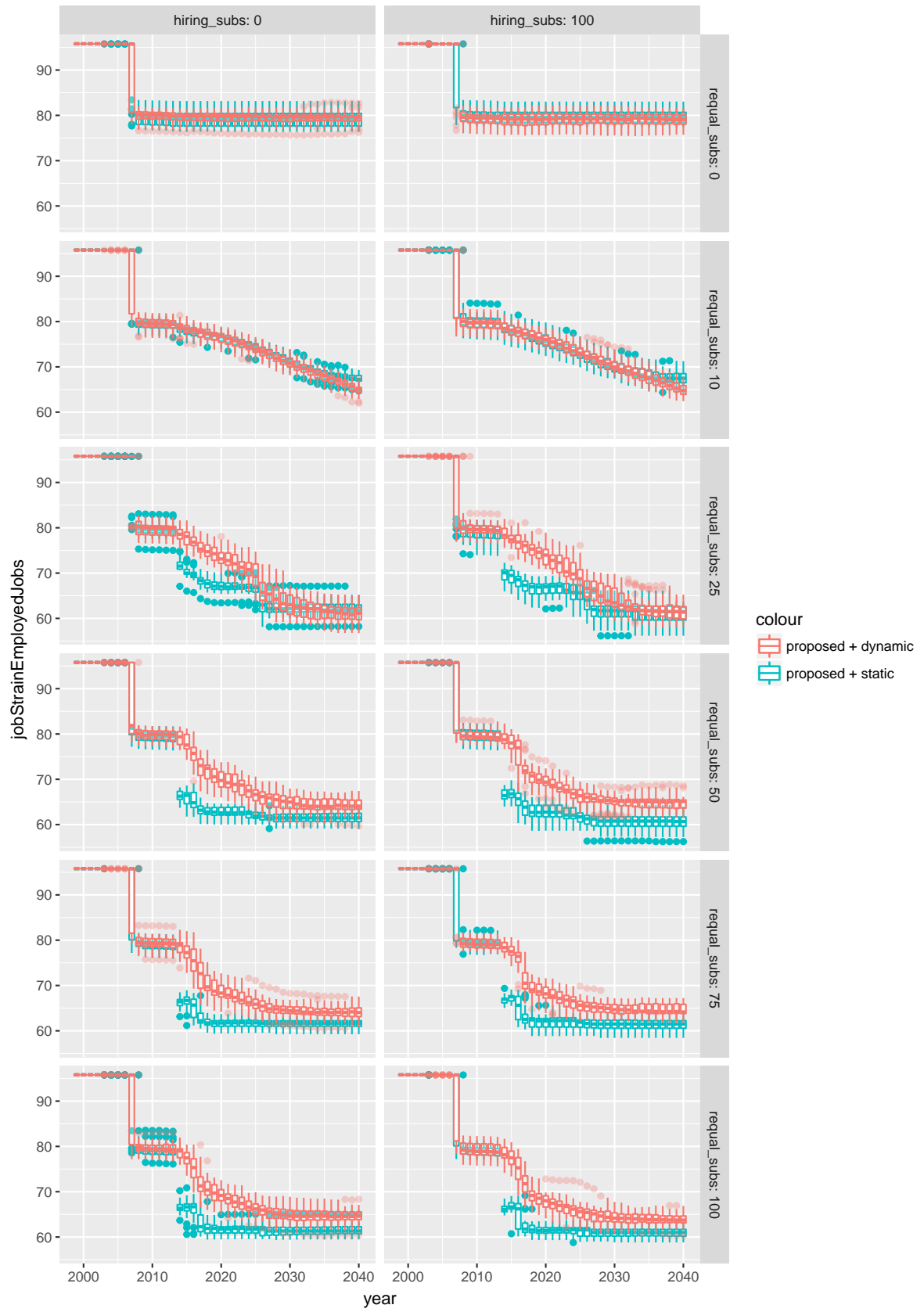
Subsidies



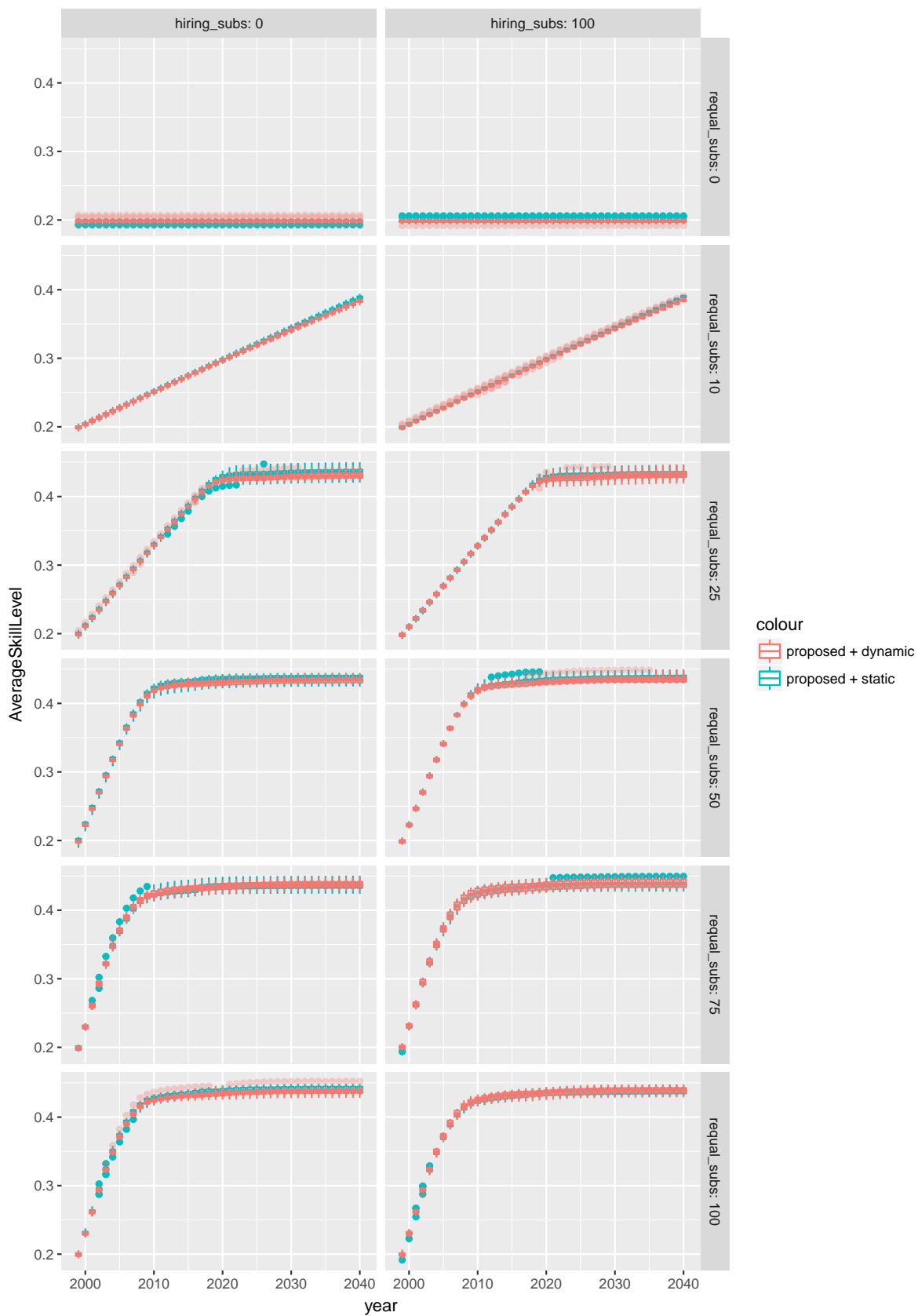
Percentage unemployed workers with different levels of annually supplied subsidies.



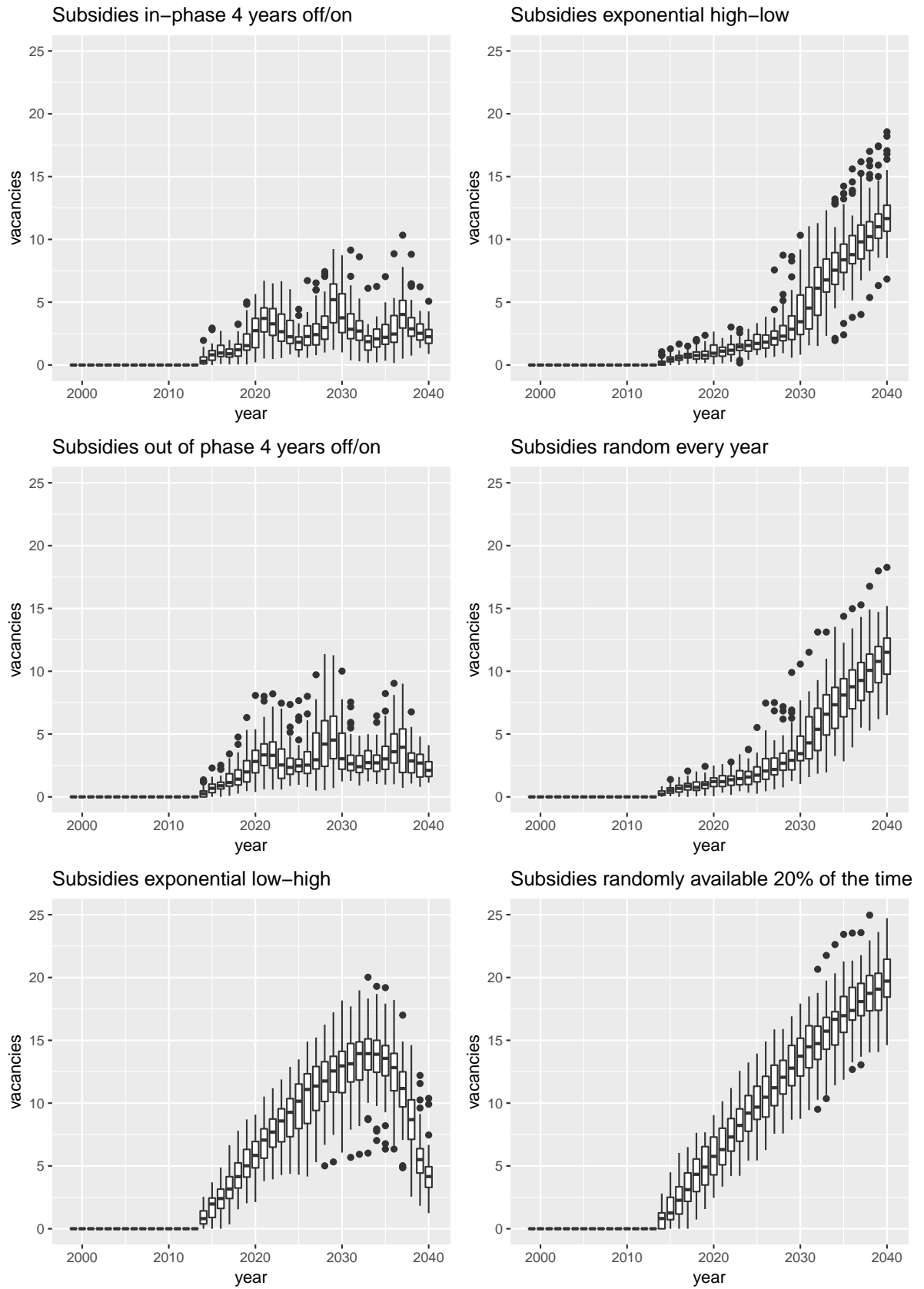
Average power of the workers with different levels of annually supplied subsidies.



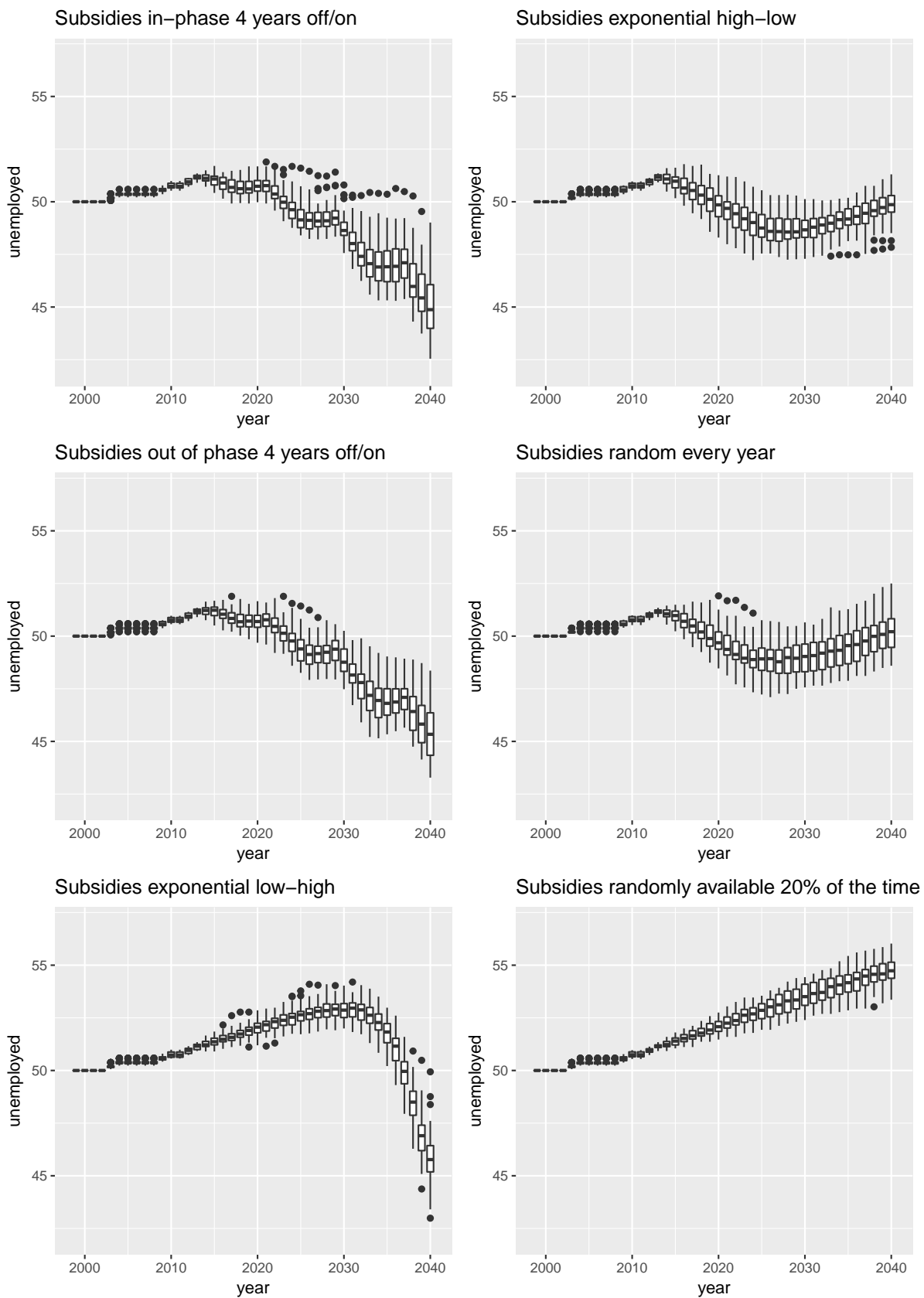
Percentage employed jobs with job strain with different levels of annually supplied subsidies.



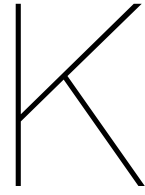
Average skill level of the workers with different levels of annually supplied subsidies.



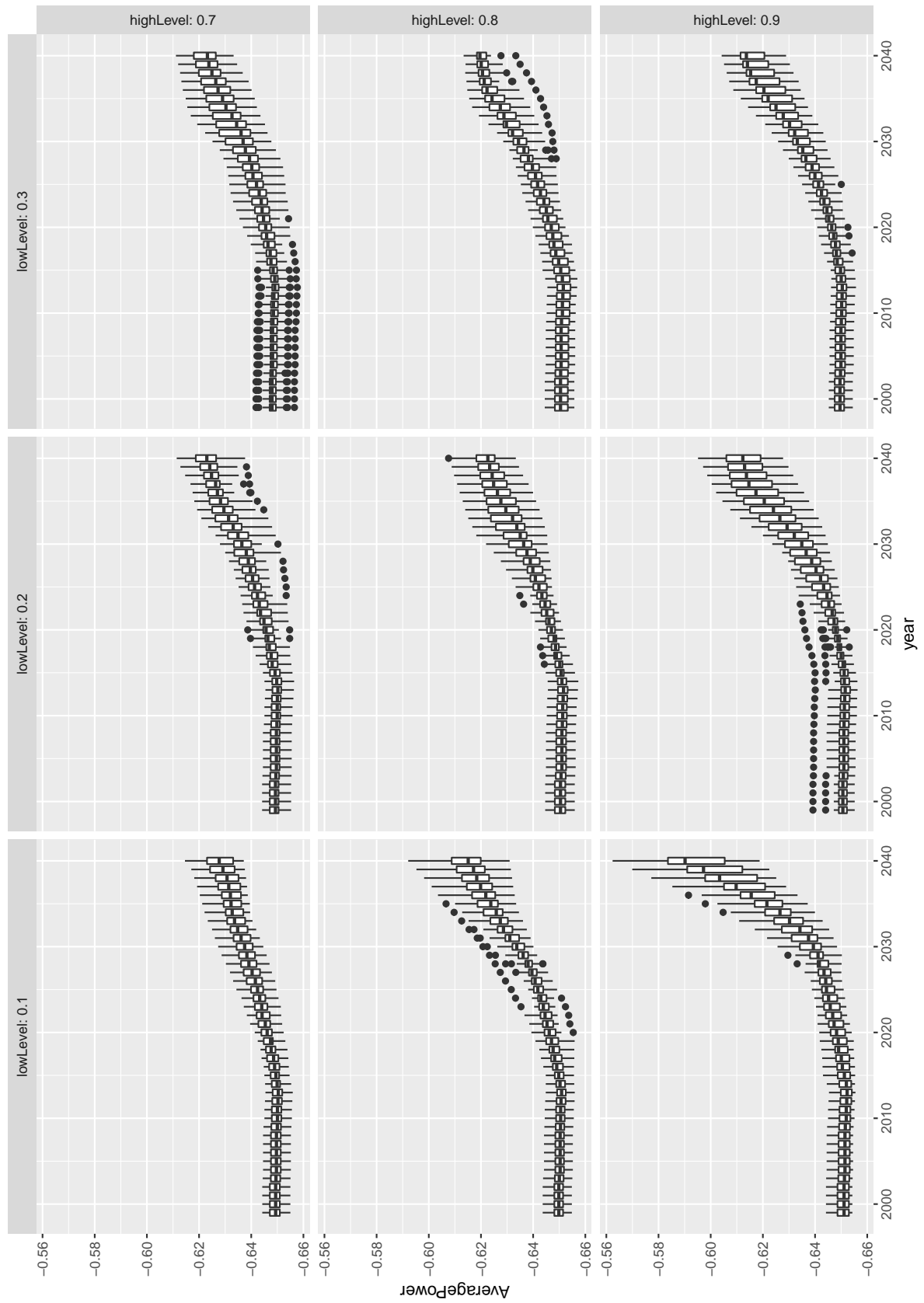
Percentage vacancies of the companies with different levels and timing of subsidies.



Percentage unemployed workers with different levels and timing of subsidies.



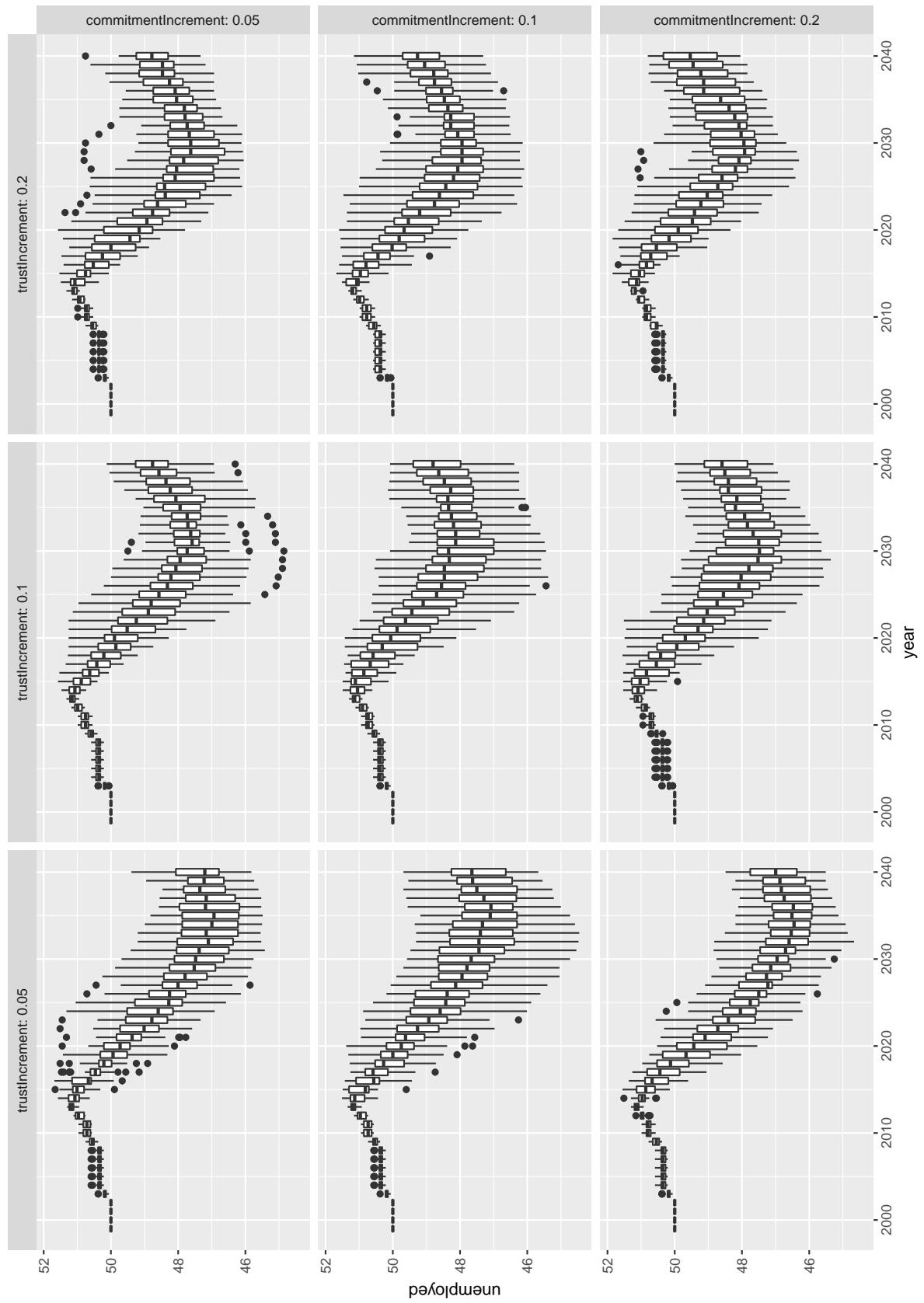
Characteristics thresholds



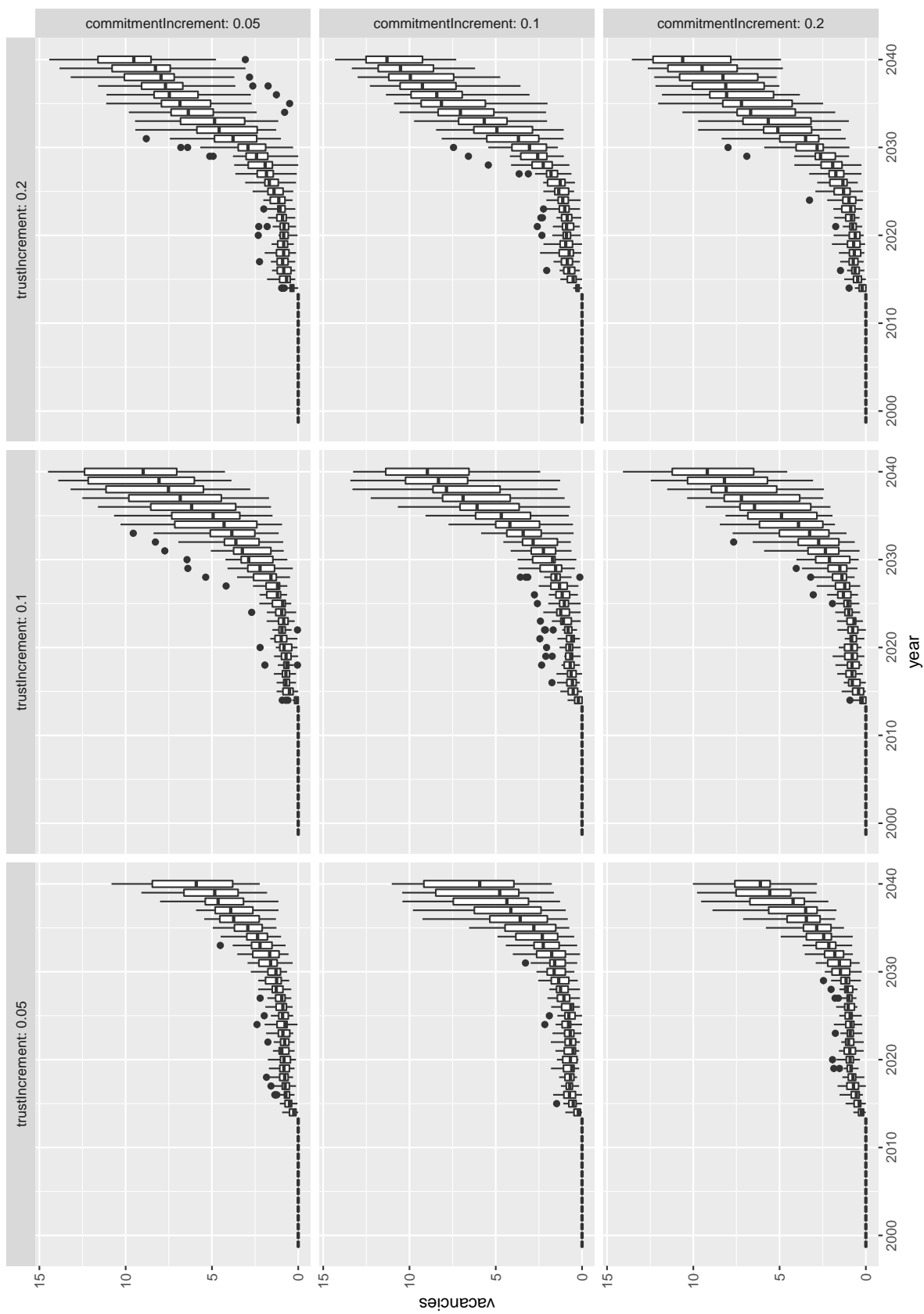
Average power of the workers with different levels of characteristic thresholds.



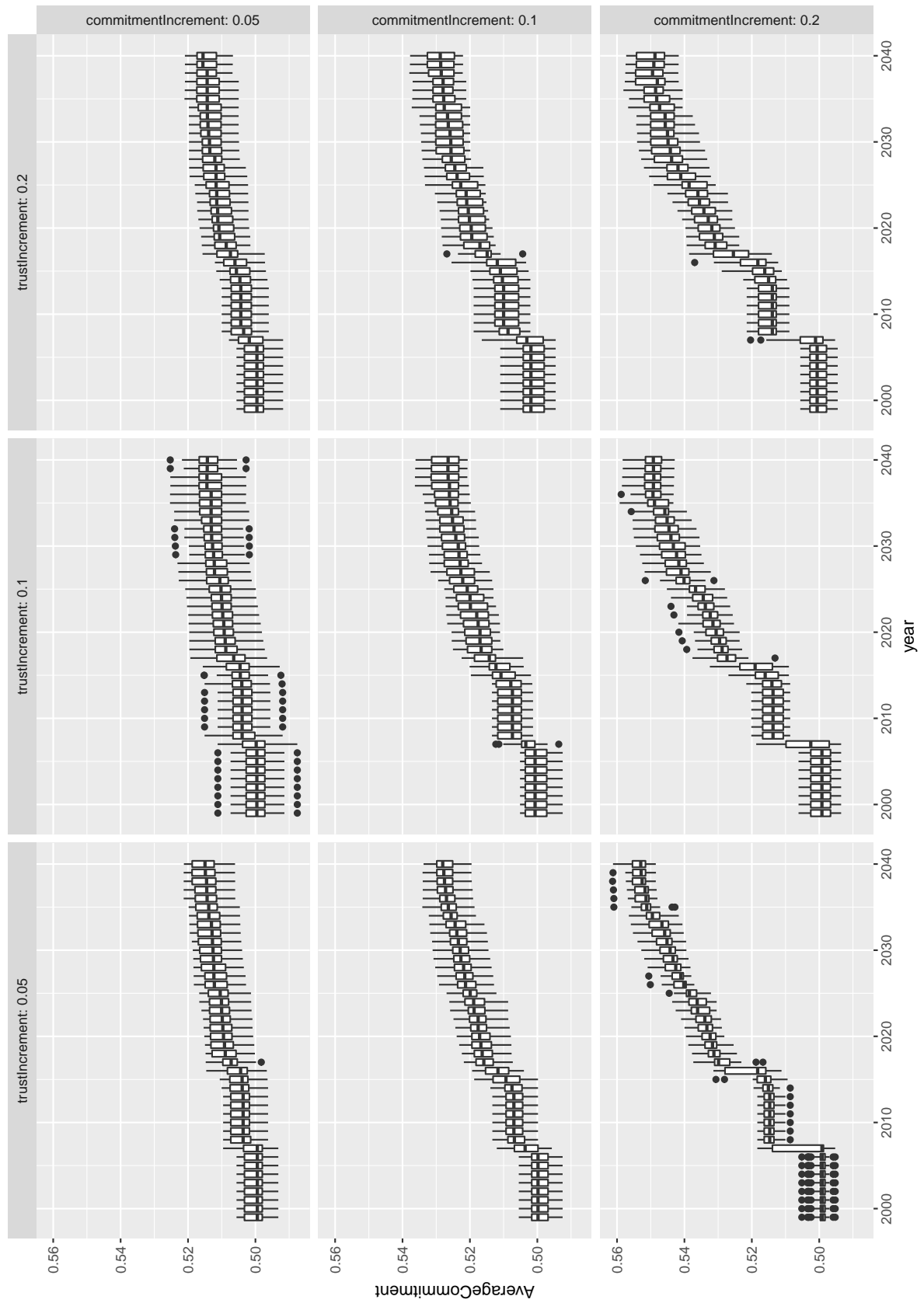
Characteristics increments



Percentage unemployed workers with different levels of characteristic in- or decreases.



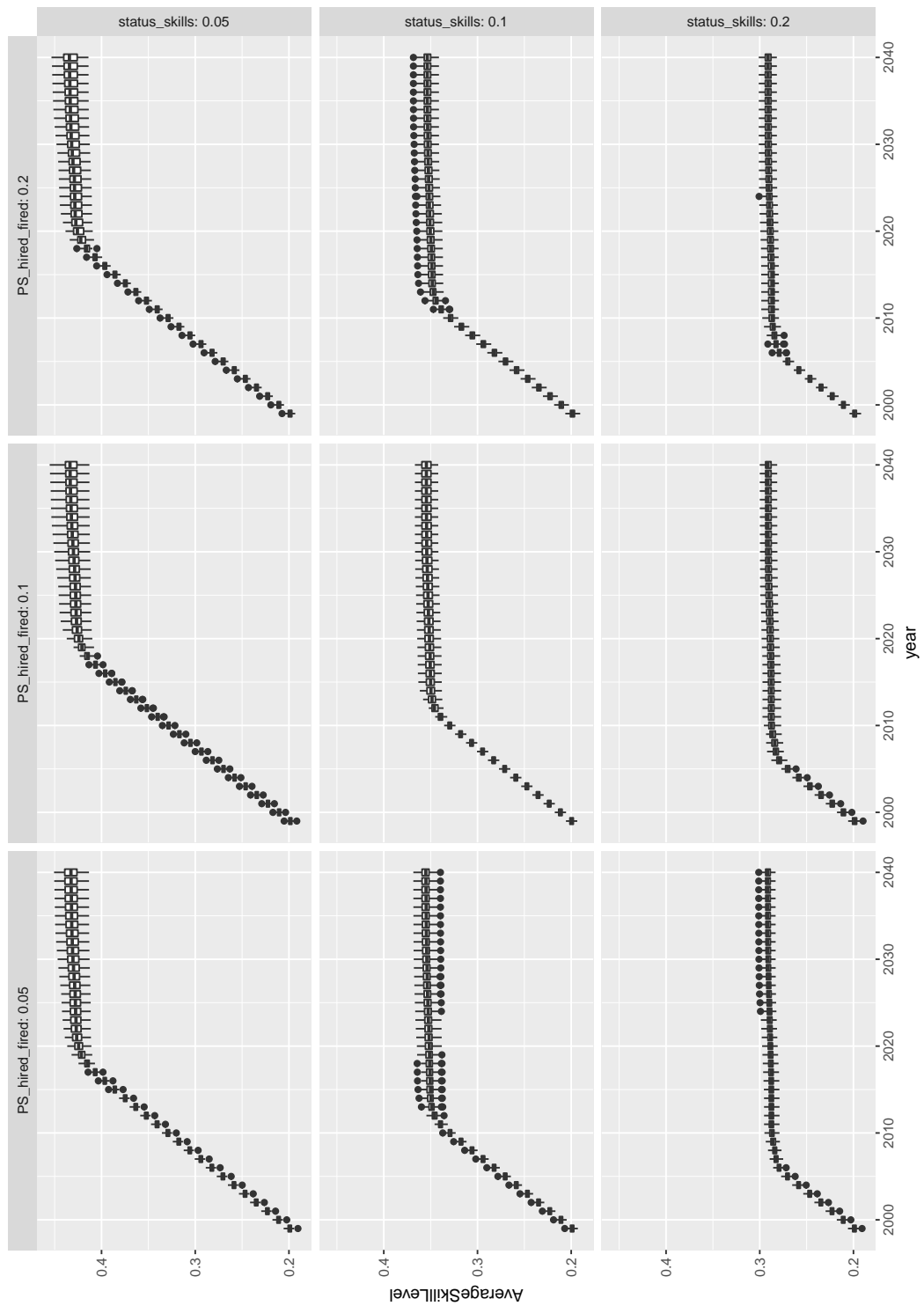
Percentage vacancies with different levels of characteristic in- or decreases.



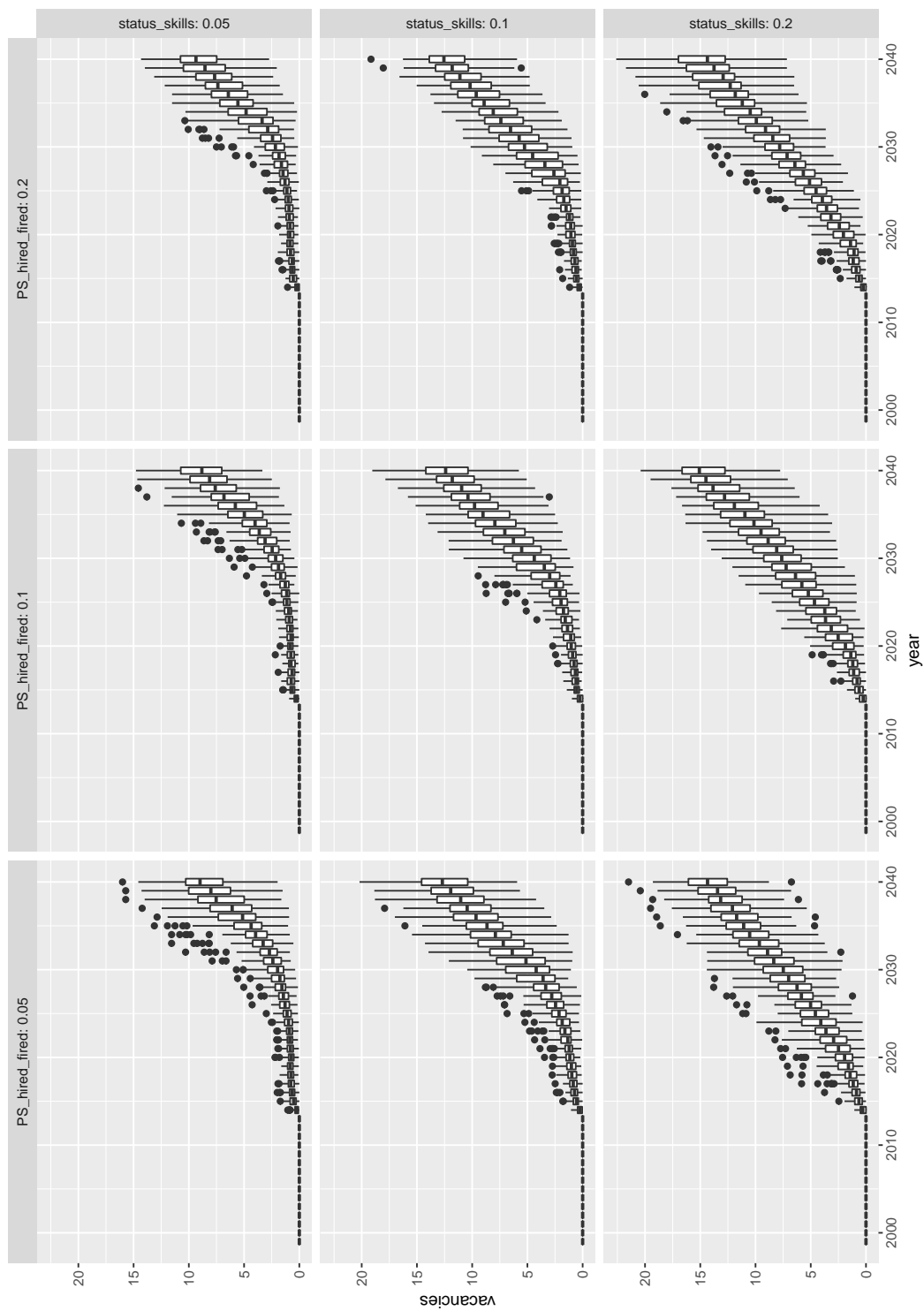
Average commitment of the workers with different levels of characteristic in- or decreases.

M

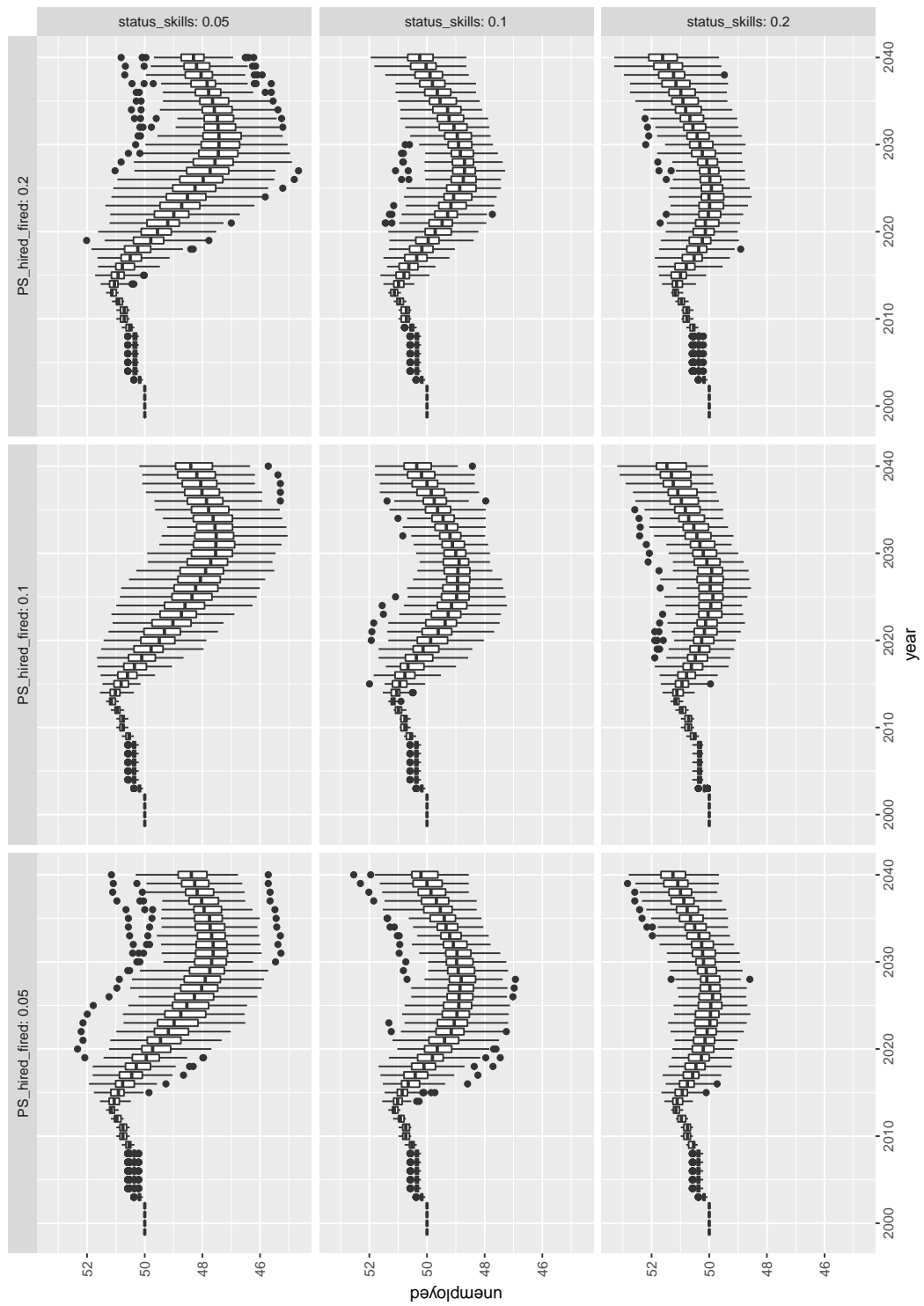
Power and status increments



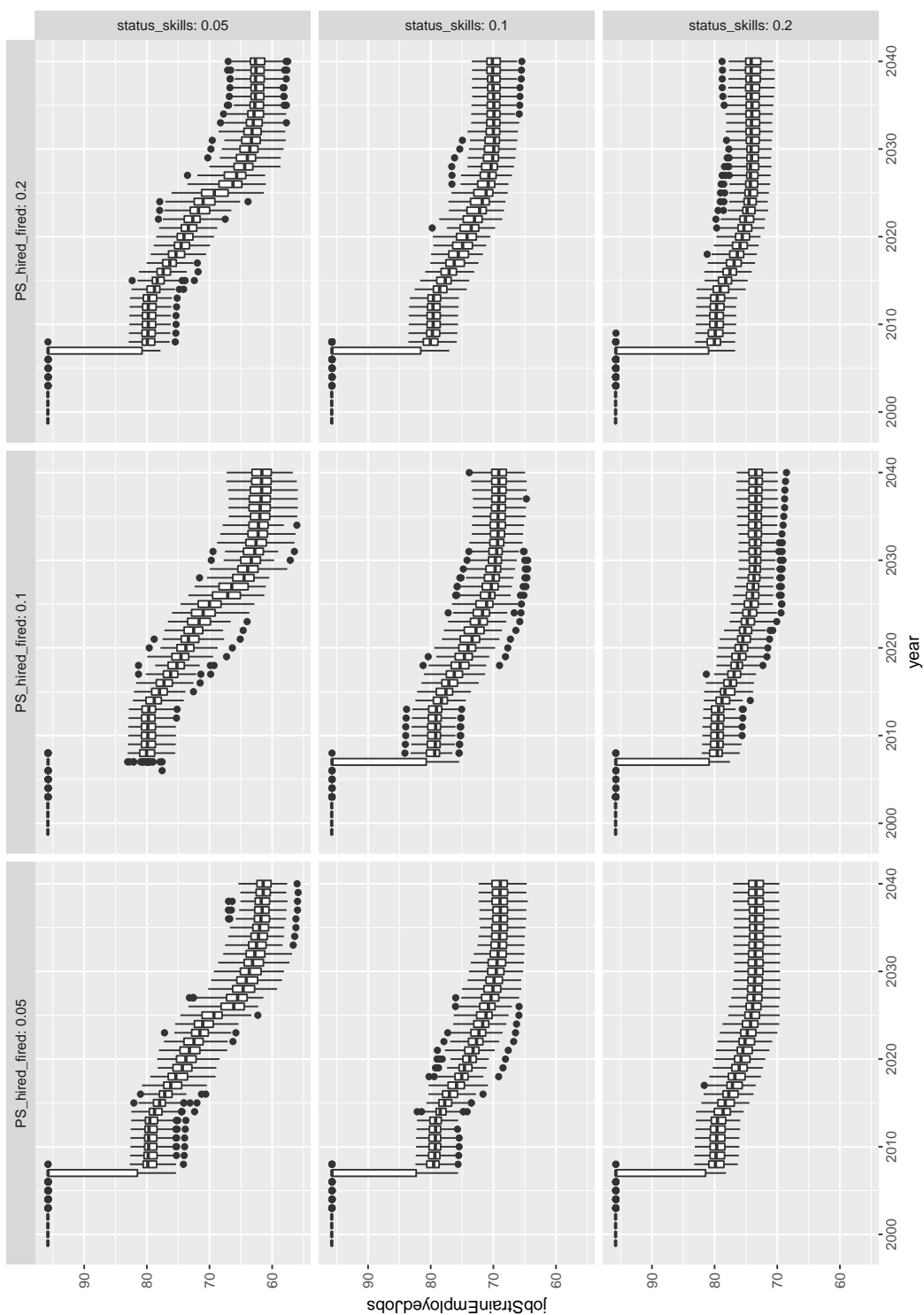
Average skill level of the workers with different levels of in- and decrease of status and power for being hired, fired, or acquiring skills.



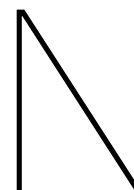
Percentage vacancies with different levels of in- and decrease of status and power for being hired, fired, or acquiring skills.



Percentage unemployed workers with different levels of in- and decrease of status and power for being hired, fired, or acquiring skills.



Percentage jobs with job strain with different levels of in- and decrease of status and power for being hired, fired, or acquiring skills.



Consultation FERAESP

The communication in and around these contacts is referred to as Carmo and Galdino (2018).

Communication to FERAESP

10-02-2018

For Alcimir Carmo (communication and internal relations at FERAESP) and Cristiano Augusto Galdino (socioeconomic studies at FERAESP)

As part of my graduation project for MSc Industrial Ecology at the Technical University of Delft and Leiden University, in the Netherlands, I have made a model that represents the sugar industry workers in Norte Fluminense, Brazil. First, there is a short explanation of my model and assumptions, and then the interesting patterns that I have found from my model results.

I would appreciate any comments and feedback on how I have represented the situation of the sugar industry in Norte Fluminense, and on the results that are produced. The case is specific for Norte Fluminense but information is obtained from researches in all of Brazil, so you could think of the model as applicable to more, similar regions.

Model

An agent-based model is built for a case study in Norte Fluminense, where the sugar industry is in decline and the oil and gas industry are growing. The working conditions in the farms and mills are bad, and mechanization is upcoming. There are a lot of social issues in the sugar industry including bad working conditions and non compliance with regulations for the jobs in the sugar industry. Therefore, a proposal is made to revitalise the sugar industry in Norte Fluminense with a biorefinery-centred agro-Industrial Symbiosis Network (agro-ISN); this is an industrial park that is said to develop the region socially, economically and environmentally. You can find the proposal for this agro-ISN in the paper of Santos and Magrini (2018), which is attached to the email.

The model described below is a very simplified version of reality. It consists of the sugar industry workers, the sugar industry union in Norte Fluminense (SISERJ), the current farms, mills, and other industries, and in the future biorefineries and other industries. They interact with each other over a time span from 1999 - 2040. So the model is also looking at a large range of possible future scenarios with the assumptions and parameters used.

The companies can hire workers, and from 2013, new biorefineries or other industries can be founded or can go bankrupt. This is randomly decided to simulate the market forces, which are not included in the model. A company is always aiming to fill all their vacancies, but can only do so if there are workers applying with the right **skill level**. If a company goes bankrupt, it fires all their workers. The **productivity** of a company is linked to the jobs that they have employed and the skill level which is required for that job. Companies can be subsidized with **hiring subsidies**; with those, they are able to hire less qualified workers than they would normally need to. The workers that are hired with the hiring subsidies learn the required skills on-the-job.

The union can be subsidized by the government to **requalify workers** (like the Renovação project from 2010, but that one was not subsidized by government?). The union also **negotiates** with the

companies to achieve better working conditions for the sugar industry workers. This happens when the level of **complaints** has reached 50% of the number of the workers in the model (an assumption). Companies comply with the unions terms of negotiation when they have had one or multiple **strikes**.

The sugar industry workers, or simply workers, are represented in their perception of **status** and **power** (because of the power struggles they have or had on the plantations), and have a certain level of **commitment** and **trust**. They also have a certain skill level, and can be a member of the union. On the basis of these elements, the workers can choose to take action. The actions that a worker can take in the model are:

- Apply for a new job
- Apply for the requalification training
- Become a union member
- Join a strike (if enough workers want to join a strike at a company, the company's productivity declines)
- Complain to the union about their bad working conditions
- Stay in the same job

All the actions that are taken influence the workers perception of their own status and power, and may change their commitment and trust.

The following things are assumed for the jobs at the companies. Each job at the farms, mills, other industries and biorefineries is simplified with a skill level from 0.01 to 1. The farm jobs require a skill level of 0.01, the mill jobs require a skill level of 0.2 (and this is the average skill level of the workers without the requalification training), the other industry jobs require a skill level of 0.5, and the biorefineries require a skill level of 0.6.

Furthermore, the **working conditions** are also rated with numbers: -2 means very bad working conditions, 2 means very good working conditions. The farm jobs have very bad working conditions (-2), the mill jobs have bad working conditions (-1), the other industries and the biorefineries have ok working conditions (0). These can all be improved by negotiations of the union with the companies.

Economics, like wages of the workers and the profit of the companies, are not considered.

The aim of the proposed situation with biorefinery-centred agro-ISN and subsidies for requalification, is to improve the working conditions of the sugar industry jobs, while keeping the unemployment of the workers and vacancies of the companies low.

Results

For experiments with this agent-based model, no real data is used, because the data is very personal (for the sugar industry workers) and not available online. For obtaining usable data, many interviews and ethnographic studies should be conducted, which is outside of the scope of this thesis. Therefore, the results are patterns that emerge over time in the model, from experiments with different input values. The patterns are described below.

- Hiring subsidies are ineffective, because the people who are hired with the hiring subsidies are not specifically aimed at a group of people.
- A slow division of requalification subsidies, e.g. providing trainings for 10% of the workers in the farms and mills every year, is preferred over trying to train for example 50 or 100% of the workers. With a high level of subsidies, the skills of the workers and the skills required for the jobs available are not correctly matched, which results in more vacant jobs than with a low subsidy divided over the years.
- The longer it takes for the union to negotiate with the companies, the more strikes there have been, and the better more companies will improve their jobs working conditions.
- With more people working in the sugar industry, it takes the union longer to negotiate with the companies about improving working conditions.

- The commitment of the sugar industry workers increases because of better working conditions in their jobs, which is also because the working conditions in the biorefineries and other industries are better than those in the farms or mills.
- The trust of the workers decreases because there are not enough jobs for everyone to be employed, when they want to change their job.
- Quickly satisfied workers do not have the ambition to acquire more skills at the job requalification trainings.
- A wide range of jobs that require all sorts of skill levels must be present in the sugar industry, because, even with the requalification subsidies, there will always be people with low skill and people with high skills.

Eventually is concluded that the sugar industry workers can switch to better jobs, defined by the job quality and skill level required. However, subsidies for requalification must be supplied, and the union contributes greatly to improving the working conditions of the jobs in the sugar industry.

Questions

Outside of the feedback on the model and results, I have some specific questions for you:

- Do you think of these resulting patterns as realistic, something that might happen in the time span of 1999 - 2040?
- Why do you think these patterns emerge; what are the drivers?
- Are the assumptions for the skills and working conditions of the jobs in the model realistic?
- Are the workers represented in a way that you recognize in your region?
- What might be the differences between Norte Fluminense and Sao Paulo?
- Would you add anything to the model to make it more complete, to represent more the world of the sugar industry workers?

Communication back from FERAESP - Cristiano Augusto Galdino

Email 14-02-2018, from Portuguese to English in Google translate and thereafter improved in English, checked and commented by Ms. Santos:

Mechanization According to official figures (UNICA - Sugar Cane Industry Union), mechanization in the agricultural area of the sugarcane sector in the State of São Paulo is now at 98%. Manual workers have either qualified or assigned themselves as operators of harvesting machines, tractor drivers (or other services dependent on machinery) or have migrated to other states, such as Pernambuco, which still depends on manual harvesting in 96%, or states like Goiás that, in addition to a migration to jobs like orange harvesting, is still dependent on manual labor because of the lack of technology there.

The problem is that in these other states, the workforce is cheap because of [1] the weak governments, which fiscally encourage [give strength to] these companies and, especially, [2] weak unions, unlike the State of São Paulo, where there are [fair] taxes and strengthened unions.

For the State of Rio de Janeiro, the scenario is close to that of the State of São Paulo [i.e. relatively stronger workforce and unions]. In the case of these workers [going] to the production of petroleum, it [could] only occur in the case of highly qualified labour, mainly due to the need for high technology [knowledge] in the sector, [however] there [might] be workers with low qualification in services such as: cleaning. Still, they can not be illiterate because the entry of these workers into the [O & G] sector is through [exams]. ==> Santos: Cleaning services are not fulfilled with exams in public institutions. They are outsourced in general.

What usually happens with most of these workers is going to underemployment [i.e. informal or illegally demanding, slave-like jobs], without qualification, not [changing] their socioeconomic reality.

Productivity, as it especially [i.e. often] is linked to the incorporation of technologies, in this case is not associated with the skills of the workers, but with [efficient] machinery.

Unions and Government Brazilian syndicalism, due to socio-cultural and political characteristics, differs from European countries. Thus, there is a need for Brazilian unions to [differentiate] in categories of workers.

In the case of the Government, for years there is no incentive to improve these workers' conditions, especially nowadays. With the reform of labour laws, the unions and labour rights have been succumbing. Employers [companies] can benefit from collective bargaining because they can now negotiate directly with the workers, without the need for the union.

Underemployment Brazilian workers, in general, and not only in the sugarcane sector, in most cases, coexist with underemployment [informal or illegally demanding, slave-like jobs], in [such a way that they] do not have defined rights. There is a huge reserve of industrial workforce. The workers undergo any type of work because they depend on them to survive and therefore can not choose between one job and another.

Replies The resulting patterns do not correspond to the reality of Brazilian workers in general, due to their high dependence on their work, even if they are underemployed.

Workers are generally poorly represented. [But] it is true that there are unions in of the states of Rio de Janeiro and São Paulo which are combative but insufficient.

It is impossible to predict, given the political [uncertainty] we are currently facing.