Bioeconomy and Regional Sustainability: Potential of Life Cycle Assessment for Food Production

Dissertation

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Vorgelegt von **Sergiy M. Smetana**, 2016

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Vechta, 12 July 2016, Sergiy M. Smetana

Abstract

Assurance of sustainability is a crucial feature for the development and comparison of regions. Currently, there is no universal sustainability assessment methodology for the integrated assessment of regional development and the possibilities of future improvement. The main objective of this thesis was to conceptualize and methodologically develop Regional Sustainability Assessment Methodology (RSAM), which would reflect the relative state of regional development through the analysis of multiple resources use by regional communities. Developed RSAM is based on adapted Input-Output Table Analysis (IOTA) applied to the natural, social and economic capital assessment at regional levels integrated through real prices monetization. Adapted indices of resource flows indicated the efficiency of internal resources use and dependency on external resources.

The application of RSAM was tested for static and dynamic qualities of regional development for the regions of agri-food cluster (the Oldenburger Münsterland, Lower Saxony, Germany) in comparison to the region with different socioeconomic and environmental parameters (Hochsauerlandkreis, North Rhine-Westphalia, Germany). High dependency of agri-food cluster regions on external resource flows and resulting higher inner cycling rates of economic resources involved in production demonstrated the active role of food production chains in the agri-food cluster regions compared to the control region. However, such beneficial economic state was limited and strongly dependent on external biotic resources with low inner cycling rates (than in the control region), which could result in deep shocking effects in the future. The analysis estimated that agri-food cluster was at the mature stage of development with stable development (resource use) without considerable changes in the period of five consecutive years (2008-2012).

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Affirmation

I hereby confirm that I wrote this thesis independently without the help of other parties and that I have not made use of resources other than those indicated. Data and concepts directly or indirectly imported from other sources have been marked indicating the source of origin. I guarantee that I significantly contributed to all materials used in this thesis.

Further, this thesis has not been used in its present form or in a similar one to fulfill any other examination requirements neither within Germany nor abroad.

This cumulative thesis is based on reformatted work which has been published (or submitted) in the following peer reviewed publications. The author of this thesis provided the main contribution to the research (concept design and theory development, acquisition, analysis and interpretation of data, drafting of manuscripts and papers' revisions).

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Abbreviations

Abbreviation	**Description**
CCI	Comprehensive cycling index
FCI	Finn cycling index
GHG	Greenhouse gases
GIS	Geographic information system
HCI	Han cycling index
IO	Input-Output
IOTA	Input-Output Table Analysis
IRIOT	Integrated Regional Input-Output Table
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCSA	Life Cycle Sustainability Assessment
MCA	Multiple Criteria Analysis
RSAM	Regional Sustainability Assessment Methodology
SLCA	Social Life Cycle Assessment
TBL	Triple bottom line
UNEP	United Nations Environment Programme
USD	United States Dollars
(C)	Cloppenburg Landkreis
(H)	Hochsauerlandkreis
(V)	Vechta Landkreis

1 Introduction

1 Introduction

1.1. Bioeconomy and sustainability in regional perspective

1.1.1 Bioeconomy progression as a more sustainable alternative

The use of bio-based products for the improvement of economic activities is not a new trend. Agriculture-based economy models are known for centuries (McMichael 1995). Nevertheless, the use of living organisms for non-food purposes triggered the genesis of new term "bio-based economy", which initially aimed at the increased importance of biotechnology and use of plant-based fuels (Eaglesham et al. 2000; Birch 2009). Over time German national and European development strategies concentrated on "bioeconomy" and "bioeconomy solutions" (European Commission 2010; BMBF 2011). This rather political term transferred to science in form of stable phrase of "sustainable bio-based economy" aimed to create "holistic approaches, essential for conflicting aims between the fields of action" (BMBF 2011; Schmid et al. 2012; Vanholme et al. 2013). Such predefinition triggered a search for sustainable solutions in forestry, agriculture and food production, which previously were in research scope of sustainable science research. Since then the main task of research on bioeconomy and sustainability is connected with aggregation of environmental, social and economic aspects to find the compromising solutions which would fit in range from acceptable to beneficial for all three domains.

The relation between bioeconomy and sustainability has a complex system character, which imposes that changes of characteristics in one system can unpredictably alter the or even totally change another system (Beckerman 2000; Bellamy and Basole 2013; Efatmaneshnik and Ryan 2016). Thus, an assessment and prediction of such changes is a key to the effective and more sustainable policies, practices and technologies. The sustainability and bioeconomy relations are not simple due to the diverse interpretation of the both terms. "Bioeconomy" is defined today as a broad concept, which includes forestry, agriculture and aquaculture, food and feed, biochemicals and biofuels, biotechnology and urban farming (Rossi and Hinrichs 2011; Nita et al. 2013; Johnson and Altman 2014; Golembiewski et al. 2015). At the same time, other authors identify bioeconomy as mainly relevant to biotechnology (Birch 2009; Richardson 2012), biofuel production (Wellisch et al. 2010; Poggi-Varaldo et al. 2014; Dale et al. 2015) and even smart agriculture (Schmidt et al. 2012; Zilberman et al. 2013). "Sustainability" has also evolved and reached a very broad definition. In most cases, it is defined as a concept unifying economic, social and environmental development equally beneficial for currents and future generations. The connections between the both concepts are very interlinked in all three pillars (social, economic and environmental). That is why multiple authors define bioeconomy as a strategy, created to achieve sustainable benefits (Golden and Handfield 2014; Pfau et al. 2014; McDonagh 2014; Morrison and Golden 2015).

Since the concept of "bioeconomy" reflects a potential path towards a more sustainable living, it should involve the use of traditional and innovative models of bio-based economy. The existing approaches in research and economy towards "tuning" into bioeconomy could be divided into three main paths. The first path (1) deals with the issues of making the traditional sectors of agriculture, food processing and consumption more sustainable by introducing more efficient equipment, adapting agricultural techniques and finding the ways to reduce the waste of bio-based products (Zilberman et al. 2013; Golembiewski et al. 2015). This path is very strong in terms of amount and a variety of conducted research and developed solutions (Karp et al. 2015; O'Callaghan 2016). Most of the research in this path is relying on traditional systems of agriculture, forest and food production and do not aim towards systematic shift of bio-based industries – "sustainable transitions" (Marsden and Farioli 2015; Crespi et al. 2016).

The second path (2) deals with innovative ways to produce, process and utilize biomass, which includes advances in biotechnology and a great application variety of new bio-based products application (Philp et al. 2013a; Philp et al. 2013b; Kumar et al. 2014). It is a very specific research intensive area which is growing rapidly, but still takes less than 2% of total biomass products on the market (Scarlat et al. 2015). Solutions developed in this path could be combined with systems from the previous path (e.g. for the development of new products) or create totally new systems of bio-based production (e.g. synthesis of bio-composite materials). Biotechnological path is still "under construction" and would need a few decades to start playing a significant role for bioeconomy progression (Wield et al. 2013; Scarlat et al. 2015).

The third path (3) includes the search for the system solutions to unite old and innovative options to create a new system shift. The examples include the research in circular economy, "sustainable transitions" and system innovations (Geels 2002; Hekkert et al. 2007; Markard et al. 2012; Borrello et al. 2016). This approach in such studies is oriented towards system level changes, which might include the combination of existing solutions and generation of new. Many scientists rely on the urgent need to take an action and argue that solutions developed within this path could bring more efficient changes in short and long-term perspective towards more sustainable society.

Even though bioeconomy is perceived as an integrative framework it is very debatable on how it will support the sustainability of development (Pfau et al. 2014). The first problem is connected with the use of “traditional” sectors of agriculture, forestry and food production. As these sectors already rely on the use of biotic component, the sustainable improvements could be performed only for the increase of resources use efficiency per unit of production. This leads to potential drawbacks of intensive agricultural production (Tilman et al. 2002; Herrero and Thornton 2013). The second problem is associated with the development of “new ways” of biotic resources use. As resources remain the same for the traditional and emerging bioeconomy sectors (and limited due to the capacity of natural production systems) the competition between the sectors grows (Tilman et al. 2009; Harvey and Pilgrim 2011). It then leads to the needs to consider the development of bioeconomy industries in “nexus” perspectives (Bazilian et al. 2011; Scott et al. 2015). Currently bioeconomy in most cases relies on the use of existing systems of biomass production taking the minor changes towards more sustainable system (path 1) and actively promotes the innovative ways to generate bio-based products (path 2). System changes (path 3) are not that actively supported due to the number of challenges associated with social acceptance of new systems, technologies development and proper management of new supply chains, uncertainties of investments and incentives, and geographical dispersion of production elements and supply systems (Borrello et al. 2016).

Therefore, bioeconomy is referred in the study as a path joining the development towards more sustainable options associated with the use of bio-based products. The need for the complex system assessment methodology and precise definition of problems restrained this study to rely on bioeconomy as a solid theoretical framework for the sustainability analysis of food related industries in regional perspective.

1.1.2 Regional bioeconomy strategies

Regional development is characterized with similar to regional and global level qualities and characteristics. At the same time there are some differences in terms of turnover volumes, spatial differentiation and aggregation. Considering the differentiation in the strategies of regional versus national development, the differences could be more significant due to the involvement of regional "…goals, policies, and action sequences into a cohesive whole" (Mintzberg 2003). The bioeconomy strategies have a conceptual differentiation between national and regional levels. National higher level of strategies aims for the policy-making in bioeconomy to provide a certain legal basis for the bio-based economy promotion. Regional bioeconomy strategies are often not that formal and tend to be formed via personal interactions between a few main actors in bio-based economy clusters (Overbeek et al. 2016).

Regional development based on principles of reliance on bio-based products has also quite similar to national strategies the aspects of TBL pillars harmonization. It ensures further socioeconomic growth while maintaining the quality of the environment. Such sustainable state of development can be achieved through the creation of a functioning model, which would satisfy social, economic and environmental needs of the population (Pavlikha and Kytsyuk 2015). Such indications corresponds to the definition of bioeconomy as a more sustainable strategy of development (Golden and Handfield 2014; Pfau et al. 2014; McDonagh 2014; Morrison and Golden 2015). Despite such a wide and uncertain vision on the regional bioeconomy strategies, it is possible to identify certain trends.

One of the common strategies of regional bioeconomy development is based on the need for the "green" investments, aimed among others on rational use of natural resources and their preservation, long term environmental security of regions in order to obtain social, economic, environmental or political outcomes with beneficial value. Quite often such investments in regional bioeconomy result in the regional specialization in a specific bio-based industry, which leads to regional cluster formation (Casper 2007). Such bio-based specialization will improve the competitiveness of a region; will increase its attractiveness for the investments; and will promote the innovation in bio-based production sector through ensuring a guaranteed market for products and services (Luhova 2015). As formation of industrial cluster is aimed to attract additional resources to the region by strengthening the competitiveness of participating companies, sharing opportunities and market expansion, then the cluster-oriented strategy of regional bioeconomy development is one of the most viable to serve as a blueprint for further strategies development. Agri-food cluster formation is also serving as the main strategy of rural regions development due to the potential of production networks to develop infrastructural and interactional foundation for the development of whole multifunctional goods and services (agritourism, new product innovations and ecological services) (Marsden 2010). This demonstrates the approach of regional development strategy based on the concepts of business clusters (Porter 1998).

The concepts of industrial cluster formation and function implies that the innovation processes in regions are not ruled by big enterprises (as it was considered previously), but rather by a network of cooperative actors, which interact in regional institutional domain (Hekkert et al. 2007; Bonaccorso 2014). Therefore, regional bioeconomy clusters are considered as forms of network structures with by multiple interacting groups aiming to accomplish common interest organizational objectives (transform biomass into competitive bio-based products) (BERST 2014).

Regional bioeconomy strategy aiming at the development of a high specialization level might result into the development of regional biotechnology cluster development. It is reviewed as "…a geographical concentration of actors in vertical and horizontal relationships, showing a clear tendency of cooperating and sharing their competencies, all involved in a localized infrastructure of support …" (Regional Biotechnology 2011) for biotechnological solutions. Moreover, the formation of bio-based industries clusters often aim the change and improvement of bioeconomy activities, rather than the governance of the region (Overbeek et al. 2016). Nevertheless, the narrow specialization of regional bioeconomy activities is a possible way for the regional development (Casper 2007).

Despite multiple sources of literature stating the benefits of cluster formation and functioning, cluster-oriented regional development might have certain drawbacks. The evidence from studies confirms that regional innovation ability might be affected in a negative way by the developed and concentrated industries in regions (Broekel et al. 2015; Njøs and Jakobsen 2016). In case regional development is based on bio-based industries progression, the lack of innovation activities forcing the advancement of bioeconomy would result into hampered regional development. Therefore, the strategy towards bioeconomy industries concentration for the regional development might be only a short-time solution, requiring further diversification of activities, potentially connected with the bioeconomy.

Another well-known strategy of regional development associated with bioeconomy sectors implies on the historical and long-term relations of regional agents as a precondition for the regional development pointing out at "industrial districts" of Beccatini and Brusco (Brusco 1990; Moulaert and Sekia 2003). From this perspective, which highlights the importance of a long-term historical development, a bioeconomy strategy building up the basis for overall regional development should rely on traditional established sectors of agriculture, food and forestry. Then the bioeconomy strategy (based on the concept of industrial districts) would refer to geographically localized agri-food or forestry productive system with strong local division of work between firms, specialized in different steps of production and supply chains (Moulaert and Sekia 2003).

Creativity and innovation are recognized as one of the drivers for the regional development in a modern world (Cooke et al. 1997; Braczyk et al. 1998; Cooke 2001; Florida 2002; Geels 2005; Florida et al. 2008; Geels et al. 2008). These initially personal qualities have an application for the bioeconomy industries as well. Innovation and creativity are important features in the promotion of known and new more effective solutions in bioeconomy (Boehlje and Bröring 2011; Wield 2013). Creative quarters (Florida 2002), system innovations (Geels 2005), innovative milieu (Maillat 1995) could be the advantage strategies for the regional development based on bioeconomy activities (Coenen and Moodysson 2009). Thus, such models form a creativity strategy of regional development.

The formalization of regional development strategy aimed at the cluster creation in many cases is not established. Historically the formation of traditional bioeconomy sectors (agriculture, food and forestry) is not planned as the driver of regional development. However, recently there has been some progression towards a planned development of regions in a smart way (Camagni and Capello 2015). Some literature indicated such strategy of regional development as "smart specialization" (Foray et al. 2009; McCann and Ortega-Argilés 2015; Morgan 2015; Capello and Kroll 2016). At the same time the application of regional smart specialization strategies in bioeconomy domain up to date is not observed.

European project "BioSTEP", aiming towards promotion of stakeholder engagement and public awareness for a participative governance of the European bioeconomy, performed an initial review on the strategies of bioeconomy on regional and national level (Overbeek et al. 2016). Despite the unclear selection of fourteen European sub-national regions the project pointed out that explicit regional bioeconomy strategies and guidelines are lacking or not publicly available. Therefore the identification of regional bioeconomy strategies as well as evaluation of the sustainable benefits of their implementation is a complicated task due to the lack of data and a holistic approach in the studies. The project also pointed towards the limited amount of official regional bioeconomy development strategies, which is also reflected in other studies (de Besi and McCormick 2015; Poranen 2015).

Researchers aiming at the analysis of regional strategies of development based on progression of bio-based products point out at the need of production networks analysis in agriculture, food industries, forestry and wood production. They point either at the need to assess the interactions of main agents as the drivers of regional cluster (Overbeek et al. 2016), or necessity to analyze “rural webs” as niches for agri-food networks (Marsden 2010), or alternative food networks (Tregear 2011).

Regional bio-based development strategies might refer to the concept of evolutional path dependence (Martin and Sunley 2006; MacKinnon et al. 2009; Coe 2010; Martin 2010) which then indicates the predetermination of regional development with traditional bio-economy industries. Even though the advances of path dependence and local industrial evolution highlighted on the importance of place and social aspects in economic geography (Martin 2010; Simmie and Martin 2010) they were not able to specify the establishing factors of paths diversification for the new conditions of regional development (Dawley 2014). Specifically, studies clarified on the structure of “lock-in” paths, but brought little attention towards the actual reasons for the paths creation. Clarity remains on the issues of regions trying to avoid the “lock-in” with old and regressing technologies and searching for the ways of de-locking to create new development paths based on innovative and progressing solutions (Martin and Sunley 2006). Moreover, paths are understood not as pre-established routes but rather as balancing interplay of approaches between following the pre-established path, its destruction or creation of a new one. Integration of ideas of adaptive structures, interconnection of local and regional institutional structures and broader technological and market pressures into more systemic approaches of local and regional evolution brought the analogues of the global production networks (GPN) approach to regional assets (Coe and Hess 2011).

1.1.3 Sustainability and sustainable transition of regions

The identification of “sustainability condition” requires a proper definition of the term. Despite a great variety of definitions available in literature (Brown et al. 1987; Costanza and Patten 1995; Phillis and Andriantiatsaholiniaina 2001; Brown 2016), in most cases they refer to the concept of “sustainable development”, set in 1987 (Brundtland et al. 1987). It contains the concept of satisfying our current needs with leaving the possibility to supply the same or higher level of needs for future generations. Such approach reveals a number of questions and issues, which remain unanswered (Voinov 2008; Brown 2016). In order to refer to the "sustainability state" this study concentrated attention on the issues of resources amount estimation, their use level identification and impact on the development trends. It should be highlighted that reviewing "resources" this study should refer to all the elements of socio-technical and environmental system.

The idea of the same consumption level of resources with same quality assured for indefinite time period clearly highlights the high level of uncertainties in "classical definitions" of "sustainable development". Moreover, if the development is considered, then it highlights the need to have more and more resources involvement in the production – consumption cycle, otherwise no progressive growing will be observed, but rather a preservation of system homeostasis (Myrdal 1974; Slim 1995). Therefore, the definition of sustainable development is contradictory in itself (Figure 1.1), as it aims at the preservation of resources for future generations and involving more and more resources for the development (Voinov 2008). However, multiple sources aim at the progression of more efficient technologies and services (comparing to the "traditional" ones) (Kemp et al. 1998; Geels 2002; Markard et al. 2012). It is an important point which might level the impact of consumption on the environment, human health and economic system and then a certain degree of impact offset is possible. At the same time the upgrade in efficiency of technologies and services triggers a rebound effect, which causes the overall increase of consumption amounts (Berkhout et al. 2000; Greening et al. 2000). All the stated arguments indicate the inappropriate use of term "sustainable development" as a contradictory and unsuitable from a holistic system perspective.

Another concept, associated with sustainability is the idea of Triple Bottom Line (TBL) (Elkington 2004), which emphasize on the need to encounter social, economic and environmental aspects in the developments (technological solutions, policies, regulations, production etc.). It searches at the compromises between these three aspects, which is a complex task. The complexity refers to the issue of development solution having a relative higher negative impact on one of the aspects of TBL. Any economic development is based on use of resources (social or natural), which at the end leads to the negative impacts on the environment. On the other hand, nature preservation and conservation, usually sets a strict limit for economic and social benefits. Therefore, TBL concept is aimed towards increase of economic and social benefits with minimization of environmental impacts. At the same time, TBL approach emphasizes on the need for compromises between these three areas (Henriques and Richardson 2013), which in most cases does not mean a rapid economic growth and development, but rather a steady progression with assurance of minimal negative impact. Hence, the regeneration abilities of environmental systems will be able to cope with relatively high demand from the other components of development.

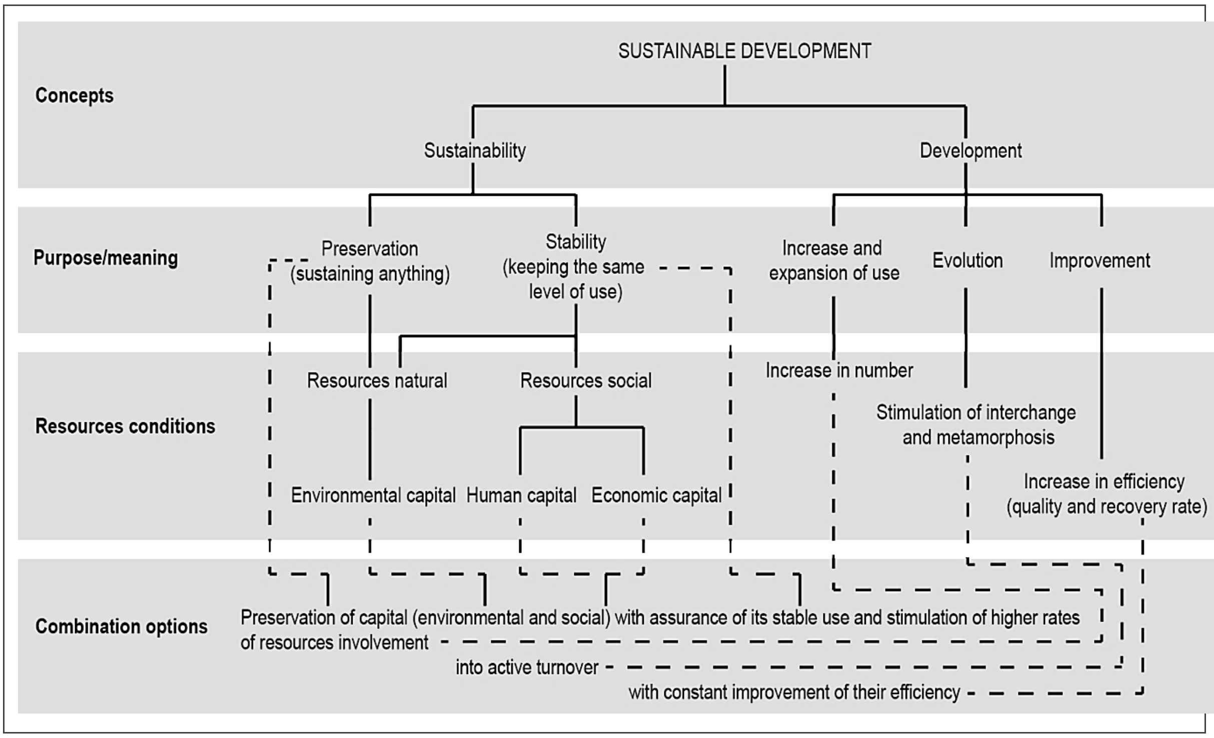

Figure 1.1: Conceptualization of "sustainable development" through resource use approach (modified from Lélé 1991)

Scientists tried to overcome the mentioned limitations of "sustainability" concepts. One of the most successful ideas is the holistic shift of society to more "sustainable transitions" (Kemp 1994; Geels 2002; Smith et al. 2010; Lawhon and Murphy 2011; Markard et al. 2012; Truffer and Coenen 2012). It aims at the holistic view of the whole socio-technological system in environmental perspective for the search of more sustainable development paths (Figure 1.2). The holism and the system vision make this concept complex for the direct application and theoretical modelling as it is involving: multiple geographic and temporal scales of interaction (Geels 2010; Coenen et al. 2012; Turnheim et al. 2015); new solutions prediction for the emerging problems and phenomena during the process of reconfiguration of the system; uncertainties and limits of prediction due to the interplay between the inertia of existing socio-technical systems and the emergence of novel ones; the need to encounter for the multiple social and environmental objectives in innovation processes; the development of a new governance system for the management of a complex system (Turnheim et al. 2015). Theoretical perspectives of sustainable transition of regions are grounded on the achievements of studies which concentrate on complex socio-technical system transitions in relation to technology innovation and diffusion, evolution economics, technical systems sociology (Rotmans et al. 2001; Smith et al. 2010; Geels 2010; McCauley and Stephens 2012).

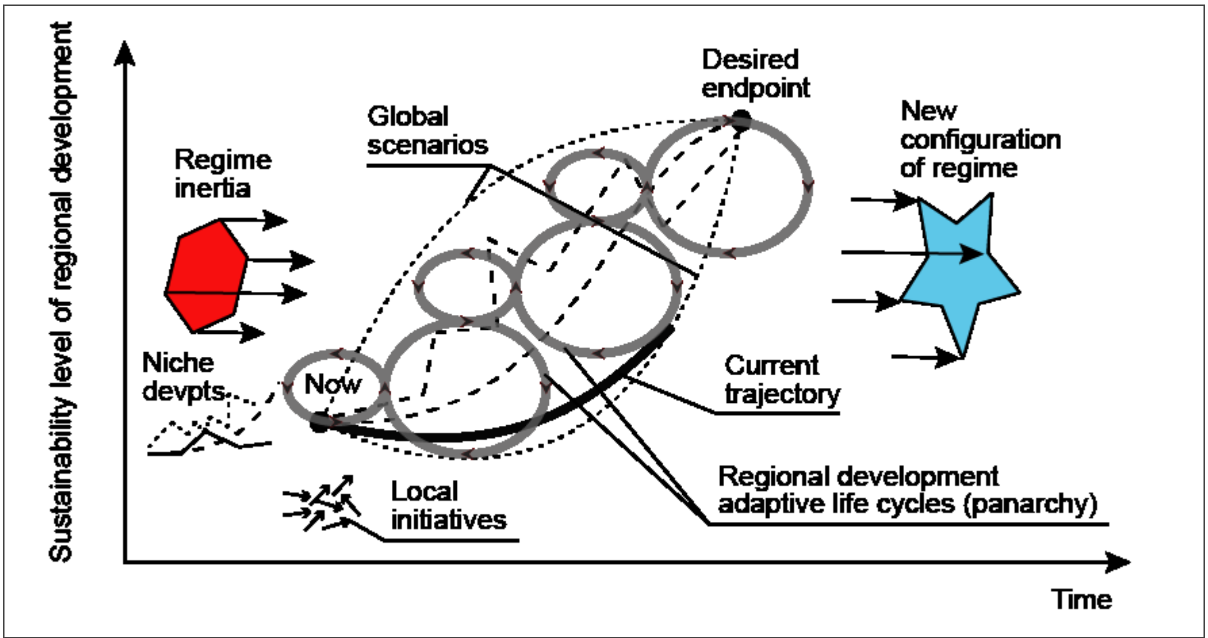

Figure 1.2: “Sustainable transition” of regional development through adaptive life cycles and niche development (modified from Geels 2002; Geels 2005; Garmestani et al. 2009; Geels 2010; Benson and Garmestani 2011; Turnheim et al. 2015)

The core model of transition dynamics of a complex system indicates that the transition is possible only if synergetic pressure is applied from multiple levels, which form multi-level perspective of sustainable transitions (Geels 2005; Genus and Coles 2008; Geels 2011). Based on previous historical conditions of complex socio-technological system, the studies review the main trajectories of technological changes based on the characteristics of co-evolving technologies and social factors. Such approach is leaving the emerging issues of transitions embedding into regional development (and changing it) without a proper attention (Smith et al. 2010). The main attention of socio-technical transitions studies is aimed at the key role of novel, niche technologies, which can shift the established and rigid regimes. This approach covers only separate cases without achieving more complex regional perspective and thus leaving the policy and planning of regional strategies without a solid support for the regional sustainability transformation (McCauley and Stephens 2012). Therefore, implementation of regional planning activities without a holistic view on regional development as a complex system might result in limitation or reverse of sustainable development transition.

Application of “sustainable transition” shift to the existing regional systems requires analytical approaches, capable to take the mentioned challenges into account. The assessment metrics of sustainable transitions should be able to be continuously readjusted, and corrected to make it capable of capturing the emerging changes of the system, analyze and systemize those changes for the prediction and correction possibilities (Turnheim et al. 2015). It is currently foreseen as one of the biggest challenges for the acceptance of “sustainability transitions” as a main governance concept (Smith et al. 2005; Loorbach 2010). Therefore, development and testing of assessment methodology, which would identify the paths of economic system development and the main drivers for the sustainable changes is foreseen as an important scientific and practical task.

1.1.4 Regional level of bioeconomy and sustainability interaction

Modern state of economy depends on the quality of global supply chains (O’Rourke 2014), which heavily rely on production and consumption in regions (Coe et al. 2008; Gereffi and Lee 2012). Environmental (resources depletion, contamination), social (workers welfare, healthcare, education) and economic (price fluctuation, globalization) issues create multiple obstacles for sustainable development of regions (Norse 1994; Leicht-Eckardt 2004; Tamásy 2013). Despite a large variety of sustainability-oriented indicators available in literature (Meadows 1998; United Nations 2007; Ness et al. 2007; Raskin et al. 2010; Eurostat 2011; Agostinho and Ortega 2012; Singh et al. 2012; Kurka 2013; Cabello et al. 2014), the estimation of regional development, its progression and the interdependency of elements can hardly be assessed with separate sustainability indicators. These problems are quite similar to the challenges of “sustainability transitions” search for assessment metrics. For example, strategic environmental assessment (as one important sustainability component) of regional planning does not identify more sustainable paths for regional development (Therivel et al. 2009). Such a disadvantage is typical for most indicators, which reveal only separate aspects of sustainability. The lack of universally applicable assessment methodologies is blocking effective regional planning, policies development and identification of regional development paths for sustainable development. That is why the need for universal and uniform sustainability assessment methodology, revealing the complex regional system, is clearly stated in literature (Dollery et al. 2007; Ness et al. 2007; Mutel 2012).

Regional (subnational) level represents one of the units applicable for the analysis of complex socio-technological system interactions (Smith et al. 2010; Truffer and Coenen 2012). It is assessable in terms of data amount, but already holds the qualities of a complex system. Complex system qualities are important for the analysis of the indirect consequences of more sustainable changes due to innovations. Previously stated challenges of "sustainable development" and "sustainability transitions" could be assessed and impacted only with quantitative interactive (dynamic) modelling of a complex system. Regional system (socio-technological system within an outlined area) represents a holding niche for the sustainability transitions (Smith et al. 2010; Coenen et al. 2012; Truffer and Coenen 2012). Such niches could be suitable for the "industrial clusters" development, which interact as a driving forces for the economic development (McCauley and Stephens 2012). Clusters are commonly recognized as optimal systems of economic innovation (Menzel and Fornahl 2009; Cooke 2013; Engel 2014; Phillips et al. 2015; Engel 2015). They usually possess common characteristics of: spatial concentration, interactivity and relationships, joint development trajectory, competition and cooperation (Porter 2000; Boja 2011; Śmigla 2014). Such complex systems with diverse characteristics requite an accurate assessment system for the effective planning and management.

Quite common national level assessment techniques reflect only separate aspects of sustainability: economic development (Lawn 2003; Costantini and Monni 2005; Kubiszewski et al. 2013; Skousen 2015), social (Spangenberg and Omann 2006; Colantonio 2011; Porter et al. 2013) or environmental dangers (Kaly et al. 2003; Esty et al. 2006; Porter et al. 2013; McLellan et al. 2014). The analyses are aimed to provide integrated results for international comparison. Regional (subnational) level of sustainability assessment has a potential to reflect the conditions both in detailed and aggregated view. This way regional level of indication represents a bridge between local resources extraction, production capacities and global trade flows. The risks associated with regional perturbations can be then accounted for the sustainable development of global supply chains. Therefore, its application for the assessment of bioeconomy role in regional development can indicate the key issues impacting the development of agriculture and food production. On the other hand, agriculture and food production in regions can play a significant role boosting their development. Such dependency of regional development on specific bioeconomy activities (food production, agriculture) highlights the importance and need of sustainability level indication and development trends estimation at this level.

Complex system interactions are not assessable with simple evaluation tools (Lang et al. 2012; Wiek et al. 2012). They require the ability of analytical system to capture the system changes, which are important for the structure and functioning of this system and other systems. As bioeconomy is perceived as directly related to sustainability, there are a few possible levels to analyze the development changes in both systems. They range from a single product level to the complex planetary boundaries. The assessment of sustainability at a product (object) level has very explicit character, which is based on the use of detailed specific data. Such approach does not reflect the system connections and changes, which are crucial for the estimation of bioeconomy role in sustainable development of a region. Global level assessment, on the other hand, unites multiple complex systems. It is based on aggregated data analysis and reflects only the biggest global trends. Comparing to the global analytical frameworks medium levels of sustainability analysis (national and regional) have a high resolution potential and abilities to reflect specific causes and changes.

Therefore, this subchapter identified the limitation of “bioeconomy” concept as a more sustainable (than “business as usual”) development strategy in regional perspective. It highlighted the need to concentrate on the assessment of agri-food supply chains as the main drivers of “bioeconomy-based” development strategy. Alongside with the “bioeconomy concept” it was identified that scientific literature deals with a wide range of “sustainability” concept interpretations. In order to exclude the misinterpretation of “sustainability” approach, it was identified that level of “sustainability” should be accounted in terms of relative use and preservation of resources (social, economic and environmental). At the same time, the holism of the assessment system should be achieved with the complex system approach for “sustainable transitions” in regional perspective.

1.2 Agri-food production and its role in the bioeconomy of regions

1.2.1 Economic value of food production

Food production is based on the exploitation of natural ecosystems in open system environments, which differs it from the closed manufacture with completely controlled production lines. Moreover, agri-food production is aimed for high quantity and high quality, which poses additional risks for the food safety due to weather, biological cycles, and goods perishability. The risks are applicable to all elements of the production chains as they are associated with their initial biotic nature. Multiple risks of agri-food production make the supply chains variable in terms of quantity and quality, which results in price fluctuations. Food prices and their fluctuations have been a topic of multiple studies, which highlighted their unpredictable character (Trostle 2010; Ajanovic 2011; Dorward 2013; Furceri et al. 2016; Jones and Monsivais 2016). The topic of food prices despite its complexity is not reflecting the whole spectrum of economic value of food production in regions.

Another economic quality of food production, which indicates its complexity, touches its differentiation from Adam Smith's interpretation of free-trade and self-regulation economy. Leaving food production and trade in a free economic flow results not in social progress, but in numerous shortcomings and eventually into the destruction of complex food supply chains (Caraher and Coveney 2016). And currently agri-food production chains are so complex that they are not managed by regional or national policies, market laws or trade factors. That is why the clarification of the economic role of food production in regions requires certain classification or grouping.

Following the publication of Sporleder and Boland (2011) it is possible to identify seven economic characteristics of agri-food supply chains with specific activities to manage them from various actors. (1) Risk emanating from the biological nature of agri-food supply chains is associated not only with the vulnerability of agriculture, but also with changes in demand and supply. The typical methods for managing the risks are connected with market predictions or assurance of supply quantities with fixed price contracts. Typically, agri-food supply chains indicate the disproportion of risks along the supply chain elements. Agricultural actors experience higher probability and magnitude of risks due to the limitations caused by the dependency on the regional factors (weather, soil quality, local social conditions). On the other end of the supply chains, retailer companies are influenced by the risks in minor degree.

Another important economic characteristic (2) is the role of buffer stocks within the supply chain. Buffer stocks could provide a certain level of security for the supply of rapidly increased demand or in case of lack of resources. They are a common means of hedging quality and quantity of conventional goods by private companies aiming to decrease the dependency on the price risks fluctuations. It is also a common practice in industries for the security of production line operation at full capacity. Buffer storages also aim for the achievement of vertical coordination in the supply chains (Sporleder and Wu 2006). However, buffer stocks are not feasible for the perishable commodities like milk or vegetables. In these cases buffer stocks are replaced with contracts with specified conditions (Sporleder and Boland 2011).

The third economic specification (3) of agri-food production is referring to the shift of scientific innovation from chemistry to biology in agriculture. It should be mentioned here that the innovation shift is not the first one in the history of agri-food production. At least three periods (each with its own characteristics and innovation foundation) can be highlighted (Gardner 2009). The first one was characterized with mechanization of agriculture, which allowed using capital to replace the human and animal labor and resulted in increased yields and lower dependency on human capital. The second period started with the application of chemical substances for the reinforcements of soil productivity. Chemical fertilizers, pesticides and antibiotics facilitated the large scale industrial agri-food production. And the third era (which is currently trying to take over) is referring to the use of agricultural biotechnology. Since 1970's the chemical agriculture was no longer able to generate significant innovation, while biological disciplines (especially molecular genetics) started defining the forefront of agri-food production. Market roll-out of first genetically engineered crops in mid-1990's shifted the agri-food production to biology as the science of tomorrow. Moreover, the advances in digitalization and information storage are predetermined the further progression of synthetic biology and complete overtake over the chemistry period. Agri-food chains, therefore, would be more dependent on the progress in the biological sciences, which might completely transform the production and supply chains and will increase the value of regional production, in case of regional specialization in the innovative fields of synthetic biology.

The next point (4) of agri-food production of economic relevance is connected with the progressive development of cyberspace and information technologies, which are starting to influence the agri-food production in Germany in considerable degree. Today the digitalized agri-food production goes beyond precise GIS-powered agriculture. Information technologies provide the opportunities for custom-tailored cost effective fresh food deliveries, which decreases the possibilities of food spoilage. Moreover, online traceability of food capacities and ordering allows for effective food recalls and quality tracking. It enables higher quality supply chain transactions at lower costs (Bailey et al. 2002; Herath and Maumbe 2014). Digitalization of food ordering and retail market would bring enormous opportunities for the market trends prediction and needed resources allocation for the production of required foods. It also solves the problem of product origin tracking, which is currently one of the biggest problems important for the consumers. Thus, information technology became an important competency for agri-food companies that can adopt global standards quickly. Information technology facilitates building interfirm social capital and vertical ties of many kinds (Sporleder and Wu 2006). Digitalization of agri-food production is changing the scope of regional food production as from one side the producers are able to deliver the goods directly to the consumers (enhancement of local food production networks) and from the other side the consumers will enhance the development of regional producers with requirement of them being more competitive than global production networks. Direct access to the global production networks allows for the "mixed preferences" behavior. Such situation will definitely pose more hurdles for the regional development based on bioproducts.

The previous economic issue is connected with additional complications of farm gate oligopsony (5), when agricultural producers have to face a competitive market with only a few potential buyers. Buyers of agricultural commodities speculate on the situation and benefit with prices dumping and market rules dictation. It results in interconnection of financial and food markets (Gilbert and Morgan 2010) and food manufactures performance as monopolistic competitors (Boland et al. 2012). While digitalization of sales might improve the situation through the collection of unbiased and statistically accurate market information to promote the long term competitive gains, it also will provide more benefits of wider agricultural goods selection for food producers (buyers). Therefore, the structure of agricultural production would continue to hold the characteristics of oligopsony. Agricultural oligopsony market structure resulted in legislative countervails and counterforces aimed to balance the market power, which resulted into the complexity of agri-food supply chains (Sporleder and Boland 2011).

The market complexity of agri-food production is related not only to the agricultural upstream but also to the retails downstream. As consumer choices dictate the rules of market performance, the relative market power shifts away from food manufacturers to food retailers (6). The power of retailers in food positioning and quantities identification dictates the producers (including the chain from farm to processors gate) “the rules of the game”. This dictation is directly related to the profit maximization (and the willingness of consumers to pay for the products) and search by the retailers for the optimization of food products placement on the market. It results in the strongest persistence of accounting profitability in retail grocery supermarkets among all the actors of agri-food supply chains (Schumacher and Boland 2005; Çakır and Nolan 2015). Moreover, the power of retail in current agri-food supply chains is interlinked also with the provision of additional information to the consumer on sustainable issues and food components origin (Lehner 2015). The request for such information is becoming a strong barrier for certain foods marketing of global and regional origin.

The last economic issue, pointed out by Sporleder and Boland (2011), is directly connected to the globalization and regionalization of agri-food production chains (7). Globalization as a complex reality was triggered by the advances in agri-food chemistry and biology, the use of information technology and technological changes. Due to the most economic changes pointed above it was possible for global food production networks to be developed, which united the fast feedback response of production to the changes in demand around the world. From one side globalization is increasing competition, which holds the prices for the consumer goods low while the prices for the raw materials are increasing. Such situation result in loss of quality of the foods or added value of goods to provide more benefits at the same price. Globalization, therefore, is transferring food production into more efficient and innovative options. Local and regional agri-food companies should account for the global tendencies and develop a competitive strategy (Busch and Bain 2004). This could account for the low use of resources and assurance of stable regional distribution channels, which can support further progression of high-value competitive products on global market. This way globalization may assure the provision of benefits for the consumers in terms of better quality or cheaper foods (Sporleder and Boland 2011). From this point of view, the development of certain means of protection from globalization (trade alliances aimed for the destruction or restructuring of the global market) might weaken the ability of the regional economy for the competitiveness. It might eventually even lead to the social isolation and limitation of regional development (Caraher and Coveney 2016).

In many regions of the World and Europe current trends are devoted to the bioeconomy development connected with three main components: agri-food systems, forestry and biotechnology. While the last component is emerging and progressing, the other components are often well established and can be considered as “traditional”. These traditional sectors are responsible for more than 90% of the annual turnover of bioeconomy in European Union (Albrecht et al. 2010). With more than 50% of annual turnover share agri-food production plays a major role in European bioeconomy. Moreover, agriculture is recognized by United Nations as the core area, which required improvement for the sustainable development (Dobermann et al. 2013). At the same time, technological progression in food industry and green revolution in agriculture influenced not only global food system, but also accelerated a spatial decoupling of food production and consumption (Fritsche et al. 2015). Such tight relation between regional agri-food production, spatially decoupled global consumption and bioeconomy progression sets specific hurdles for the regional development. The bioeconomy is foreseen as “glocal” feature, which connects the global food trading system with local markets and agricultural production capacities (Teräs et al. 2014). As an example, relatively low costs of modern efficient transportation of resources benefit regional development, but also bring additional risks to energy-water-food nexus in other regions (Johnson and Altman 2014). This is a typical example demonstrating the influence and importance of bioeconomy for regional development. Therefore, the bioeconomy is transforming the rural economies in a vital rate as they are more dependent on the production of biomass comparing to the units of larger scales of socioeconomic organization.

Regional food production is usually perceived as economic activity which provides substantial direct, indirect and induced economic benefits to local and regional communities (La Trobe and Acott 2000; Mount 2012; Lutz and Schachinger 2013). While there is much evidence that promotion of regional food production could be an effective strategy for the development, some researchers point out to the need of substantial tests of such theories, as there is not enough significant assurance of the links between specific localized food production and regional economic development (O’Hara and Pirog 2013;

Pinchot 2014). Others argue for the weak linkages between local food production and regional development (Deller and Brown 2011). On the other hand, agricultural production and purchasing, without a local focus, are known to cause the outflow of funds from regions (Pinchot 2014).

Global tendencies, however, do not indicate the relation of bio-based economy development and agri-food production systems at sub-national level. As the role of agri-food production systems varies for different regions, their impact on the regional development level differs accordingly. Some regions are characterized as centers of agri-food production and, therefore, they should be reviewed as areas of increased importance in case a region follows a bioeconomy-based path of development. In some cases the centers of agri-food production are formed due to favorable climate conditions as with olive or wine production (Banks and Sharpe 2006), specific location as with seafood production (Carr et al. 2003), or successful management of economic activities as with intensive industrial meat production (Tilman et al. 2002). The development of agri-food production centers (clusters) is coherent when the production is identified and limited to objective reasons (climate, specific soils, location). The aspects of such regions sustainable development are predefined and, therefore, the search of sustainable solutions should be performed within the limited framework of "natural conditions". Regions of intensive agri-food production often do not have objective reasons for their genesis in a specific location. They are often initiated with a complex of preconditions such as transportation infrastructure development or market emergence. The bright example is the development of the most intensive livestock production center of Germany in the Oldenburger Münsterland (districts of Vechta and Cloppenburg in the west of Northern Germany). Despite poor soils in the regions the development of agri-food production center was triggered by developing transportation infrastructure and evolving market. Intensive livestock production in the region caused the further development of processing industry and emergence of "hidden champions" (Tamásy 2013). The acceptance and progression of bioeconomy in Germany triggered additional activities around the agri-food production in the region (Klohn and Voth 2008; Tamásy 2014). Intensive application of manure to the soils allowed growing crops for biodiesel and biogas production. Joined activities of various agri-food related enterprises and service providers activated the economic growth of the region and it became "a very prosperous rural space" to live in (Klohn and Voth 2008; Tamásy 2013; Tamásy 2014). Most common characteristics of agri-food cluster formation (spatial concentration, interactivity and relationships, joint development trajectory, competition and cooperation) are observed. Thus, such development of industrial enterprises in a cluster is often seen as absolutely beneficial for regions and local communities (Delgado et al. 2014; Delgado et al. 2016).

1.2.2 Social role of agri-food flows

Social aspects of agri-food flows represent an important sustainability dimension, which has not been holistically tackled in scientific literature in a satisfactory degree. It is clearly observable while reviewing the issues of social changes for sustainability transitions (Di Masso et al. 2016). However, certain attributes were highlighted in this direction, concentrating on livelihoods, social capital, social integration and generational replacement. There is rarely a simple correlation or connection between a particular food flow and certain social effects. However, while individual consumption of the same food might have variations in meaning (daily consumption, special events or snacking “on the go”) the capacity of food flows and their direction could identify the social role of food. At the same time the analysis of separate issues does not provide a holistic image on the relation between global food network and complex ecological and social relationships, which calls for the development of a single framework capable of reflecting on integrated economics, health, environment and social issues (Waltner-Toews and Lang 2000; Lang 2009; Rideout 2012; Heller et al. 2013).

Agri-food flows are interlinked with the use of multiple raw materials and resources. While considering the social role of the food production, it should be accounted that the flows encounter people as elements of the flows. In this case the social element plays a role of capital resources which is represented by a wide spectrum of studies (Devine-Wright et al. 2001; Adger 2003; Kamruzzaman et al. 2014; Lee et al. 2016). The integration of agri-food flows and socium is dual. From one side food plays its role as a tool in social life (Lind and Barham 2004; Starr 2010; Guptill et al. 2013). From the other side, social capital is a resource of agri-food flows generation, maintenance and restructuring. The second quality indicates the abilities of the human resources to be substituted with the other forms of the capital (Dau 2015). Such a quality indicates the possibilities of reduction of human capital use for the intensive agri-food production. Intensification of agriculture and urbanization of global population decreased the “popularity” of agricultural activities. Belgian scholars mentioned that a century ago 80% of households were concentrated in the agricultural sector; while today's agricultural employment represents only a minor part, especially in developed countries (Swinnen et al. 2012). Timmer also highlighted the ongoing trend towards "agriculture without people" and "a world without agriculture" (Timmer 2009a; Timmer 2009b) indicating the decline of employment importance and economic value of agriculture in the European Union economy (Swinnen et al. 2012).

A different approach of social role consideration deals with the livelihood approach. This approach encounters the necessities of human needs to develop relevant strategies, social environments and capabilities (Allison and Horemans 2006), rather than supplying societies with plentiful resource load. In terms of livelihood being sustainable it should also account for such characteristics as capabilities of maintaining and recovering from stresses and shocks with maximal preservation of the natural resource base (Serrat 2008). These characteristics directly deal with resilience and a self-sufficiency of human communities, which aim both at support of long-term productivity of natural resources and livelihood provision for regional communities (Scoones 1998; Ncube 2012).

The duality of agri-food flows and communities reflects on the biased aspects of social integration and reproduction. From one side without resilient agri-food flows the social integration and reproduction will be set under the critical conditions. But another side of material integration of social reproduction between different regions reflects on economic capital reorganizing human capital and leading to the changes of the historical order of agri-food production. It is referring to the globalization issues, when the globalized community is creating new interdependencies and destructing the possibilities for the resilient livelihood of the local agri-food workers (human capital) and local vendors. The consequence of such integrative global food flows might be the diminishing of the social role of agricultural workers (most of them are women) in the global South and the destruction of capabilities for self-sufficiency of local communities (McMichael 2005). Moreover the globalization of food production and consumption causes the homogenization of westernized cuisine cultures through the supermarket chains (Andrews 2008), disconnection of social interactions from the local food cultures and collective belonging (Fischler 1988; Newman and Jennings 2012). Some authors argue, that globalization of food production chains caused the creation of "obesogenic environment" as a result of the interaction of cultural, environmental, genetic and behavioral factors (Boehmer et al. 2006; Patchett et al. 2014; Daniels et al. 2015). The feeling of attachment to the specific region is crucial for the development of food communities as the place and the shared ideas of collective (Shwaluk 2009). This way, through the food flows, social interactions become a source of regional unity and meaning (Keller 2003).

The review of literature on the social impact of agri-food flows indicated the limiting number of publications on the role of food as an education factor. For example, food plays an integral role in socialization and cultural assimilation processes of children education and integration into the social structure (Messer 2007). Food is perceived as a part of communication, ethnographic feature for building social solidarity, identity, and family life. The association with regional food triggers the affiliation to a specific regional community, which keeps people connections to those regions and holds the possibilities for cultural dissemination. It is still unclear on the positive or negative impacts of culture dissemination of regions in the global areas as it leads in many cases to the distribution of world cultural "superfoods", prestige foods, body-image foods, sympathetic magic and physiologic food groups. It seems to add to the diversity of regional cultural traditions, but at the same time it might completely replace the ethnic cultures, as it is happening in African countries with the import of cheap western culture foods (Rundgren 2015a; Rundgren 2015b). It brings attention again to the specific existing need to find the links between human nutrition, food habits and aspects of culture and society (Messer 2007). Fairly few publications point at the socially related means in the decreasing of negative impact on the environment. For example popular in many countries food recovery for social purposes is a great example of positive effect achieved via the use of social factor (Bilska et al. 2016).

The characterization of food as "specific from a region" identified possibilities for the indication of food flows as those holding signs of cultural identity. Such social features (associated with specific premium and competitive qualities of foods traditionally produced in a region) promote the success of the regional economy based on agri-food production. Social food performance, therefore, could be a factor of success of regional economy development, which includes further related benefits as tourism (Bessiere and Tibere 2013). At the same time, the origin of food and food traceability identification is a factor of economic competitiveness, which includes strong market mechanisms for leveraging of agri-food flows rather than the assurance of food "uniqueness" and "faithfully" (Savoja 2011). From this point of view, "social awareness" and "conscious consumption" paradigms aimed for the avoidance of global superfoods hegemony over the regional foods are not fulfilling the criteria for more sustainable foods, which calls for the local production and consumption.

Food flows interaction with society is multidimensional and affecting all the spheres of human life. It is connected with our work and leisure, celebrations and communication and directly interlinked with our happiness and wellbeing. Therefore, the perception of agri-food supply chains cannot be production centered as this would lead to the perception of food as a crop delivery agent to the plate in geographies of food (Whatmore 2002). The consumption centered theories in their turn concentrate on social practices, meaning and identity of food without relying on the physical (natural) aspects of food production and distribution (Goodman 2002). However, using the system vision on the food flows and assuring system security it is possible to achieve the compromising state of sustainability (Kuzmin 2016).

Agri-food flows are associated with a community nutrition and livelihood through a very specific notion of delivery of food functional properties. Currently, the linking of statistical information (representing an average) on food production and consumption with the quality of nutrition in regional communities is a challenging task. Despite the progress in the amount and diversity of information available on the agri-food flows, the efforts aimed to connect the agri-food production and health in communities are hampered due to the continues increase in the complexity of food systems (Hawkesworth et al. 2010). The challenges are associated with the complexity and inequality of nutrition even at the smallest local scale. Inequalities in the regional food nutrients distribution remain and cause severe extremes from causing 35% of child deaths to the death-related epidemics of obesity (Haslam et al. 2006; Black et al. 2008; Hawkesworth et al. 2010). The use of averaged data therefore does not reflect on the malnutrition or obesity problems for the different parts of the community. The indication of the critical points for the health issues through the social demonstrations is not the right approach, as food has always been a last holding point for the population during the historical times. People could survive numerous shortages, but the food was the last indicative point which triggered communities for the riots. In modern times, hunger riots do not play the same substantial role in Western countries as before (however the hunger is still a powerful factor in many developing countries). But even today it is impossible to diminish the influence of the food crisis impacts on the local and regional communities. It is especially obvious with the impact of global food demand and supply changes (Rideout 2012; Moodie et al. 2013; Caraher and

Coveney 2016), which in its turn triggers the "food related" riots as a form of protests for the "unfair" benefits distribution along the supply chain (Rideout 2012; Caraher and Coveney 2016).

Multiple social issues discussed above can be viewed as causes and the results of distant relations between production and consumption decisions. The lack of profit related connections between different actors of agri-food flows is partially solved through the structures of vertically integrated corporate entities. But the externalization of negative impacts associated with social health issues or environmental damage obscures the feedback to farmers, consumers and other players. Moreover, ignoring the negative issues of food production to the people causes the generation of positive feedback loops, which reinforce the dominant food system (Rideout 2012). Slow acceptance of "unfair" foods creates the demand for the higher quantity of the product. Higher production and availability not only causes the wider acceptance of the goods, but also decreases the importance of "more traditional" alternatives. The development of "more traditional food" moves to a niche market and slowly disappears together with the loss of knowledge and skills needed for the production.

"Clustered" development is beneficial for regions in terms of economic and social issues. At the same time environmental aspects are often neglected during such development. Growing population and increased demand for food (per capita) versus limited area of agricultural lands creates a precondition for the lack of land resources. In order to circumvent agricultural crises, intensified by the competition from biofuel production side, the sustainable land use and management are essential. A few main "trend" solutions have been proposed and used in various regions of the worlds. One of the most widely used is an intensification of agricultural production. Intensive methods employ chemical pesticides and fertilizers to produce greater amounts of food and feed. In terms of land use they are more efficient than extensive ones, but extensive use of chemicals may cause higher environmental impact per unit of production and overcome positive effect from increased productivity (Mattsson et al. 2000). The same disharmony is observed in the regions of intensive meat production. Modern methods of pig, poultry and livestock production have higher efficiency of meat produced per area, the workers involved, or per capita. At the same time high concentration of meat production cause high concentration of animal excrements, moral and ethical issues connected with animal and hired workers' well-being, increased use of drugs in production etc. (Tilman et al. 2002; Tilman et al. 2011; Bäurle and Tamásy 2012; Tamásy 2013).

Another popular type of agriculture, which finds its supporters, is the organic production, when crops and animals are grown without the use of chemicals, "the natural way". At the same time such production acquires more lands (comparing to intensive alternatives). Many papers have been published, where authors come to conclusion that the organic crops production is more efficient than conventional (Pimentel et al. 2005; Hoeppner et al. 2006; Deike et al. 2008; Gomiero et al. 2008; Guzmán and Alonso 2008; Meisterling et al. 2009; Lynch et al. 2011). Gomiero with coauthors in their review (2008) found that in global perspective organic versus conventional farming is less energy intensive (60% less per unit of land, 30% less per unit of yield). Other authors also support that statement from the perspective of biodiversity preservation, energy use, greenhouse gases emissions, which is based on the lower use of synthetic and mineral fertilizers, pesticides and herbicides (Küstermann and Hülsbergen 2008; Pimentel and Pimentel 2008; Pelletier et al. 2008; Mondelaers et al. 2009; Lynch et al. 2011). At the same time it is true not for all the crops and meat production management systems (Küstermann and Hülsbergen 2008; Lynch et al. 2011; Venkat 2012).

The main trends of regional development associated with agri-food chains result in intensification of industrial development (concentration of industrial enterprises, intensive industrial agri-food production) and increased competition for the resources with related industries (bio-energy, biotechnology). Despite the overall positive impact of industrial intensification on regional development in a short-term perspective, certain factors could affect the development in evolutionary perspective. Resource scarcity and environmental impact could diminish the positive effects of industrial concentration and production.

1.2.3 Environmental impact of agri-food supply chains

Sustainability as a scientific concept is currently suffering from "sustainability fraud" when common misconception of sustainable development, revealing it only as an economic or social development. Environmental security and social equality often remain aside. Such a situation does not correspond to the TBL idea of all three fields united in equal degree to supply today's needs of humanity and guarantee the future generations rights for the same level of resource supply (Elkington 2004). The economic development of regions, based on biotic products, goes side by side with the impacts on the environment causing the negative fluxes for ecosystem services and human health (Simboli et al. 2015). The agriculture and food production are responsible for the vast amounts of the wastes. Livestock growing and meat production is the single sector of economy using the largest amounts of land (26% of ice-free terrestrial surface of the planet). Feed crops production adds to the number and raises it to 33% of the land surface or 70% of all agricultural lands. It is also responsible for 9% anthropogenic CO_2 emissions, 37% anthropogenic methane (23 times higher than the global warming potential of CO_2), 65% anthropogenic nitrous oxide (296 times higher than the global warming potential of CO_2), 64% of anthropogenic ammonia emissions (Bunte and Dagevos 2009). Social issues arising from the negative impact on the environment (health problems, aesthetic perceptions) and ethical issues (animal welfare, workers welfare, unfair trade policies) also become an important force in the development of regional societies (Tamásy 2013). The Oldenburger Münsterland is not an exception – it is characterized with intensive agriculture and food production as very powerful economic boosters, but at the same time they are the causes of negative impacts for the environment and society. It is a bright example of production sustainability estimation problems. Despite obvious problems in the region, it is unclear which components are more important for the regional development and which should be improved or changed. The solution for the indication of a more sustainable path could be identified with analysis of the regional development as a complex system. In this case the assessment system should account for multiple aspects of regional development. Thus, it is necessary to review the available sustainability assessment methodologies, capable to identify the problem areas of sustainable development in the region and variations for the further development.

The future of food production on a global scale is affected by multiple factors: increase of population in around 30-40% by 2050 (Pimentel and Pimentel 2008; FAO 2009), increased demand of food per capita, population urbanization, land scarcity (biofuel production, erosion, desertification and deforestation), climate change, environmental pollution, etc. Taking into account all the conditions and uncertainties in the scenarios, global food production should be increased by 70% by 2050 (FAO 2009). It means that annual cereal production will need to rise to about 3 billion tons (2.1 bln. tons today), meat production will need to rise to 470 million tons (270 mln. tons today). Mentioned trajectories of world development, increased global demand for crop calories and proteins, decline in crop yield rates by around 2% (FAO 2009), extensive agricultural land use and intensification of animal production (Tilman et al. 2011) set a pressure on the rate of land use (Mattsson et al. 2000). The estimation of the average increased pressure on environment does not reflect the regional differentiation. Certain regions are more vulnerable due to the increased value of biodiversity (Myers et al. 2000; Seto et al. 2012a), water scarcity (Chapagain and Tickner 2012; Hoekstra et al. 2012), land and soil resources depletion (Fischer et al. 2010; Lambin and Meyfroidt 2011; van den Bergh and Grazi 2014), certain foods production concentration (Ramankutty et al. 2002; Lee et al. 2012). Therefore regions have different vulnerability to the critical events. As the weakest element in the chain indicates the resilience of the system, the hotspot regions indicate the sustainable limits of global food supply chains. That is why, effective regional planning should rely on the identification of regional hotspots and their impact on sustainability of development.

Food production (including land conversion and agricultural land use) cause the biggest impact on climate change among all the sources. Greenhouse gas (GHG) emissions from this integrated source are estimated to be at least 2.5 times higher than total emissions from global transport (IPCC, 2007; World Resource Institute, 2005) and forecasted to double in the nearest 50 years. Only this single reason might cause the most negative scenarios forecasted by scientists and therefore it should be treated as of highest importance. That is why a search for a more sustainable proteins sources, agricultural practices and food sources diversification is becoming more and more actual (Harvey and Pilgrim 2011).

At the same time agriculture has a significant GHG mitigation potential, which is estimated at levels of 1600-4200 Mt CO_2 eq. annually (Smith and Olesen 2010). Using this mitigation potential as a basis for alternative farming systems might be a solution for more sustainable agriculture and food production (Pretty et al. 2005; Flugge and Abadi 2006; Khan and Hanjra 2009; Smith and Olesen 2010; Macintosh and Waugh 2012).

Modern food production system is a part of a complex bioeconomy system, which involves production of other bio-based products. Growing biofuel crops and using them as an energy source has a negative drawback effect, rarely stated in literature. The use of energy crops (oil crops, wood, biomass) has an effect of GHG cycles dynamic acceleration (Cherubini et al. 2011; Hall et al. 2012). The burning results in gases (mostly CO_2) emissions in the atmosphere at increased speed comparatively to forest and agricultural systems, when the captured carbon is stored in the plant, animal, human tissues for years (Hall et al. 2012; González-García et al. 2012). Such "nexus" effects should be accounted at the planning and management of agri-food supply chains.

Food production is affecting climate change not only through the GHG emissions, but also with enormous consumption of water resources. Only agriculture itself is responsible for 70-80% of all human water consumption (Garnett 2013), some authors rise that number to 92% of global water footprint (Hoekstra and Mekonnen 2012). Such an amount of water consumption is not caused by the influence of climate change, but rather by the agricultural (poor) management techniques (Sun et al. 2013). Most of the water used for agricultural needs is coming from natural sources: "green" rainwater (74%) and "blue" water from surface resources (11%), but such distribution is rather an average, because water footprint has a high spatial differentiation (Hoekstra and Mekonnen 2012). For example, certain districts of China are characterized with more than 90% of blue water footprint (Sun et al. 2013). Water footprint, together with other examples, indicates the high regional variability in terms of agri-food production and associated effects.

Summing up, agri-food production is currently the main player in bioeconomy-oriented regional development. It forms the driving forces for socioeconomic development, industry concentration and specialization. At the same time, agri-food production is based on limited or steadily reproducible natural and social resources which create certain limitations for the continuous development. Such situation in a short term could be solved with the supply of the resources from the other regions, which would make the region of agri-food production an industrial hub of development ("industrial cluster"). The concentration of resources and production capacities results in increased impact on the environment due to the concentration of emissions and increased density and volumes of transportation. In this case often the management of social resources becomes a vital issue for the existence of the cluster and development of the region (Morosini 2004). Such issues, which cannot be easily solved as they are in conceptual contradiction to the concept of production capacities concentration, misbalance the regional system. In many cases such misbalance triggers the redevelopment of a region, its shift towards more stable system or even eliminates all the benefits from the previous development.

1.3 Globalization and regionalization of agri-food clusters

1.3.1 Globalization of food flows

Globalization is a controversial and debatable issue, both due to variations in definitions and possible impacts on the society, economy and the environment. From one side food globalization is viewed as “internationalization of trade” which is supposed to ensure the constant supply of food products to the consumer (Senauer and Venturini 2005; van Witteloostuijn 2009). From the other side regionally increased production of goods calls for the production capacities concentration, industrialization of production and reduction of food diversity (Oosterveer and Sonnenfeld 2012). International trade in agri-food production is stably growing (Porkka et al. 2013; D’Odorico et al. 2014). The core of such a growth is not only in the growing population, but also in the urbanization of the world population. By 2050 the urbanization level is predicted to reach almost 70% (United Nations 2014). It is triggering the development of food production centers, capable of supplying the good on a constant basis and in big quantities.

Urbanization of society and development of agri-food production centers create conditions for the development of “teleconnected” agri-food flows. Intensification of “global interconnectedness” reflects social, environmental and economic relations between remote regions (Yu et al. 2013; Moser and Hart 2015). Such stable international transfers of biomass and money between regions pose dangers for the resource depletion and social tensions from one side (Lenschow et al. 2016) and socioeconomic benefits from the other side (Requier-Desjardins et al. 2003; Anderson and Valenzuela 2007; Bhagwati 2007; van Witteloostuijn 2009). Therefore, globalization might promote sustainable development in one region at the expense of another region (Lenschow et al. 2016). In Chantham House Report the scientists (Lee et al. 2012) identified twelve most economically significant global food trade flows which took various directions and which were composed of different food and feed products (Figure 1.3). Their analysis indicated that the regions of import were Europe, East Asia and China, while the exporting parties were in Americas, Australia and Africa. Such distributions correspond to water scarce areas identified by Mekonnen and Hoekstra (2016). Global agri-food flows are becoming a serious force impacting the development of regions in a complex multi-dimensional spectrum of sustainability issues.

Global food flows are responsible for 12-25% of globally produced and consumed food (D’Odorico et al. 2014; United Nations 2015a; MacDonald et al. 2015; Nesme et al. 2016). Despite such big and growing numbers, most food is still consumed domestically and locally. Large international companies are responsible for only 3-5% of world food sales (van Witteloostuijn 2009). At the same time for some products (coffee and cocoa) the share of export reaches 80% of production. International trade is growing in absolute numbers, while in relative is slightly declining, which reflects the increase of internal food production for the most countries (Oosterveer and Sonnenfeld 2012). It corresponds to the simple logic of Ricardian comparative advantage theory in international trade, when free movement of capital and labor affects the countries specialization to increase their comparative advantage (Wood 1991). Large food companies, working with a few elements of supply chain, will benefit due to the global placement of thevarious parts to increase efficiency. Small food companies, at the same time, will operate in the local market and benefit from local communities support. This will result in consumer surplus with diverse foods with competitive prices and innovation stimulation (van Witteloostuijn 2009).

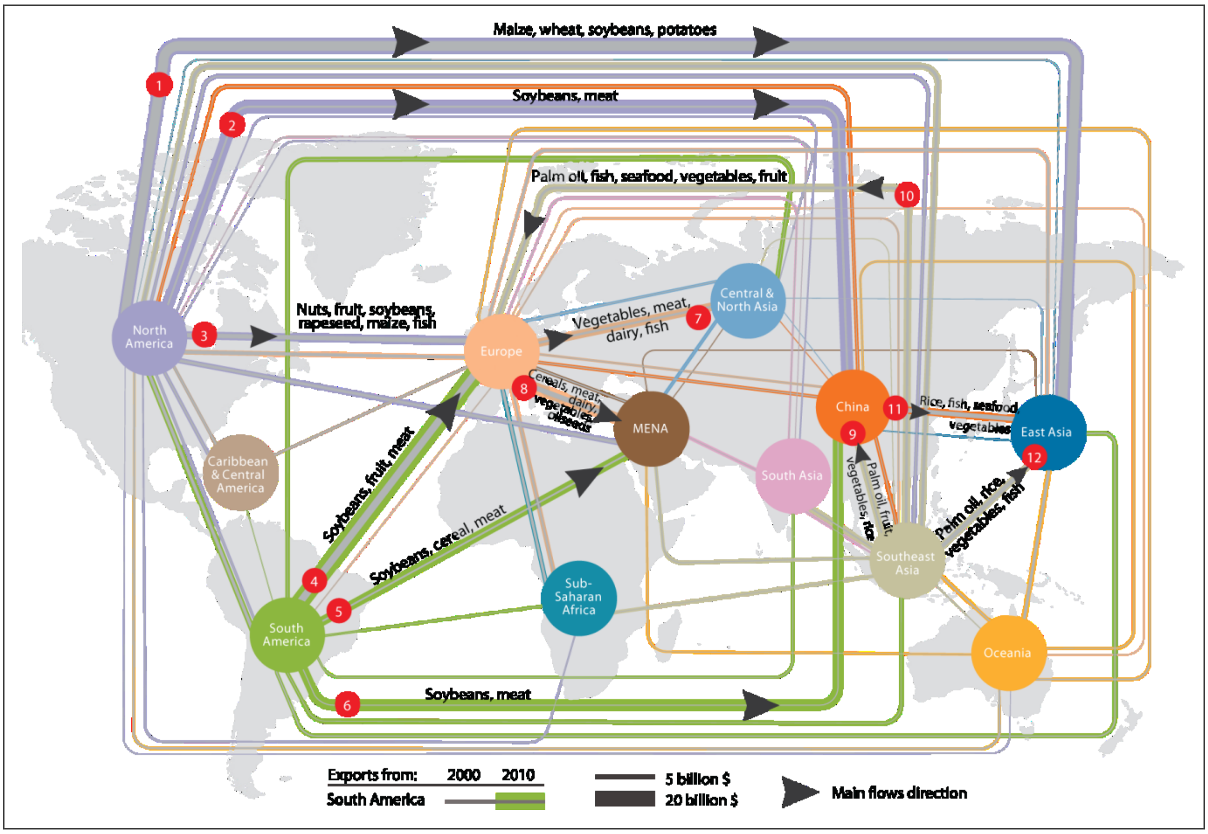

Figure 1.3: Main global agri-food commodities flows and their dynamic from 2000 to 2010 (modified from Lee et al. 2012)

International food trade poses continuously increasing importance of national supplies (Porkka et al. 2013), distribution of land (Kitzes et al. 2009; Meyfroidt et al. 2013; Bergmann and Holmberg 2016) and water resources (Hoekstra and Chapagain 2011). It interchanges thread effects between world regions through the intensification of regional shocks. On the other hand, more effective food production in one region in comparison to the other could lead to the decrease of water consumption in world regions, due to transfer from “business as usual” crop production to bioeconomy-related with significant decrease of water consumption (Rosegrant et al. 2013).

Increased international trade and globalization of food is changing the location and patterns of food production (Fader et al. 2013; Meyfroidt et al. 2013; D’Odorico et al. 2014; Alexander et al. 2015). Around 20% of global cropland and agricultural water is allocated to the international food consumption (Hoekstra and Mekonnen 2012; Kastner et al. 2014; MacDonald et al. 2015). This way the negative environmental impact and outsourced food security of food production is shifted to other regions, which creates multiple social conflicts (Fader et al. 2013; Meyfroidt et al. 2013; O’Bannon et al. 2014; D’Odorico et al. 2014). The quantification of drivers and implications of food supply globalization is an important task, which should be solved to understand the possibility of sustainable regional development (Foley et al. 2011; Meyfroidt et al. 2013; MacDonald et al. 2015).

Van Witteloostuijn in his research identified five propositions for the future research of globalization impact on the food production and distribution (2009). In his opinion globalization will: (1) bring additional benefits to gain from scale and scope economies; (2) boost the love for variety and convergences of taste at consumers, which will result in larger fluctuations of critical events and expanded peripheral supplies of resources; (3) increase benefits of generalist food companies due to the market concentration (globalization) in the food industry; (4) benefit the specialist food companies along the supply chains owing to the increase of market density (regionalization) in the food industry; (5) result in specialist activities growth in the food industry (triggered by stronger effect from density increase than from concentration effect) on one side and boost for globalization (concentration of industries) from the other side. Such propositions clearly rely on the “glocalization” concept of regional geography (Swyngedouw 1997; Aminy 2002), when globalization and regionalization co-evolve in parallel into the emergence or further proliferation of dual market structures, with generalists and specialists viably operating side by side. Some products then will be locally produced and consumed, others locally produced and globally consumed, and yet others globally produced and globally consumed (van Witteloostuijn 2009). The complexity of relations between regional development and globalization, therefore, should be clearly identified and measured to estimate the potential paths for more sustainable development which assures balanced socioeconomic and environmental development model functioning for generations. The assurance of such model functioning we perceived in this work as sustainable development of a region.

1.3.2 Changes and challenges of agri-food cluster development

"Glocalization" evolutional perspectives identify a few possibilities for the regional development paths. The first one is the "localization" – specialization of the regional development on supplying own needs with own resources. In case of reliance on the agri-food production as a main driver for the regional development this path would mean the limitation of economic and social development due to the limited nature of environmental resources. At the same time, supplying only own needs might not require extensive amount of resources. Regional development, based on own environmental resources has a limited nature and is characterized with multiple disadvantages (Sachs 2000). Land locked regions or island regions usually suffer from such development paths. The second possible development path is "globalization" – specialization of the region on the production of agri-food processed and preprocessed commodities demanded on the global market with the utilization of agri-food raw resources from other regions. In this case the region serves as a transformation center, changing raw resources into the "ready to consume" product with an added value. The added value allows profit to remain in the region boosting its development. In this case some negative impacts of the production are outsourced, but due to the high density of production in a region a share of influence remains in the region, causing multiple issues. A bright example of such region is the Oldenburger Münsterland, which relies on external supply of feed for the intensive animal production (Klohn and Voth 2008; Tamásy 2013; Tamásy 2014). The third type of the regional development dependent on the agri-food supply chains would be a combination of two previous ("glocalized" development). It could rely on global food supply chains to satisfy regional needs, or use regional natural resources to produce commodities demanded on the global market or more complex combinations when regional demand and supply is partially connected with the global agri-food flows. "Glocalization " of regional development involves increase of concentration and density of specialized enterprises within a specific area (Brenner 2003) which leads towards the development of industrial clusters.

Industrial cluster formation and development is a widely discussed phenomenon in literature (Porter 1990; Ellison and Glaeser 1997; Porter 2000; Brenner 2004; Menzel and

Fornahl 2007; Alecke and Untiedt 2008; Delgado et al. 2014; Delgado et al. 2016). Industrial regional clusters are often defined in studies as “industrial districts”, “industrial local clusters”, “innovative milieu” and “regional innovative systems”, following the goals of economic success analysis of certain regions comparing to other ones (Brenner and Gildner 2006). Moreover, studies highlight multiple ways to identify clusters (Brenner and Gildner 2006; Cruz and Teixeira 2010; Śmigla 2014; Delgado et al. 2016). Despite a great variety of types, approaches and theories of industrial regional clusters, most scholars come to terms that: clusters are geographic concentrations (agglomerations) of related industries and associated institutions (Rosenthal and Strange 2003; Cruz and Teixeira 2010; Delgado et al. 2016); their formation is following a life cycle composed of development, expansion and mature stages with probability of destruction at the end (Maggioni 2004; Menzel and Fornahl 2010; Brenner and Schlump 2011; Martin and Sunley 2011); clusters formation is beneficial for a region (higher innovativeness, more employment and economic growth) in development and expansion stages; and might cause negative effects at mature stages of life cycle (Grabher 1993; Brenner and Gildner 2006; Menzel and Fornahl 2009). The concept of cluster life cycle was developed from the similar concepts of product and industries life cycles (Brenner and Schlump 2011). It also corresponds to the main stages or patterns of regional evolution: development (growth); steady (climax) state; and regression (degradation) (Garmestani et al. 2008; Simmie and Martin 2010). Moreover, similar life cycle is observed for the most complex systems with non-linear character, which could be characterized as an adaptive life cycle (Martin and Sunley 2007; Garmestani et al. 2008; Garmestani et al. 2009; Martin and Sunley 2011; Allen et al. 2011b).

Cluster genesis and structure should be studied from dynamic perspective as they (like complex systems) are distinguished with non-linear path dependence on regional development (Brenner 2004; Iammarino and McCann 2006; Martin and Sunley 2006; Menzel and Fornahl 2010; Boschma and Fornahl 2011; Ter Wal and Boschma 2011). The complexity of the topic is also highlighted with the abundance of the studies on different theories of cluster life cycle (Bergman; Menzel and Fornahl 2010; Martin and Sunley 2011) and a clearly stated immature status of the appropriate analytical framework and theoretical basis for the proper conceptualization of hypotheses (Boschma and Fornahl 2011; Martin and Sunley 2011). Despite such hurdles the separation of a few “static” stages of industrial cluster development provides an approximate framework for the indication of cluster genesis impact on the sustainability of regional development. Indicative, the initial stage of agri-food cluster development is reflected in minor negative impact on environmental resources and minor positive impacts on socioeconomic state of a region. Further, the expansion stage bears significant negative impacts on the environment and positive changes in the structure of socioeconomic resources. Mature and declining stage of cluster life cycle based on agri-food supply chains results in some redirection of social and economic resources to bring the positive impact on the environment, while the overall social and economic conditions suffer negative consequences of cluster transformation or decline.

The research on agri-food cluster development deals with multiple definitions of: "local or localized agri-food systems" (Requier-Desjardins et al. 2003; Bowen and Mutersbaugh 2014; Chiffoleau and Touzard 2014), ''alternative food networks'' (Bowen and Mutersbaugh 2014), "agribusiness cluster" (Geldes et al. 2015; Theuvsen and Tamásy 2015), "agri-food cluster" (Phillips 2012). Despite the wide variability and different accents of cluster definitions they all rely on a few common characteristics, which define their properties. Initial stage of industrial cluster formation linked to agri-food production is associated with lands occupation by the emerging companies in a scattered pattern (Klepper 2007). Further growth of the cluster is associated with companies' expansion, multiplication (start-ups and spin-offs (Brenner and Schlump 2011) and partnering with universities and research institutions (Menzel and Fornahl 2007). This initial stage of clustering could characterize most agrarian regions as activities of firms could gain a certain level of economic development without reaching a critical mass of activities needed for further development of a cluster (Brenner 2001). The reach of critical mass is determined by the local conditions (availability of environmental resources) and number of firms located in the region relevant to the established supply chains (social resources) (Porter 1998; Boschma and Wenting 2007).

The accumulation of critical mass of economic, social and environmental resources leads to the expansion or development stage of a cluster life cycle. The market for the relevant agri-food supply chains at this stage expands tremendously, relying on Marshall's agglomeration economies (Maggioni 2004). The expansion of the market and increase of production capacities prompts the synergies and interactions between companies, which are also not directly associated with the agri-food supply chains, but provide indirect services. For example, the development of agricultural center would result not only in the development of robust farm enterprises and processing industry, but also into the development of agri-food machinery repair workshops and service industries for the workers. Moreover, "the spillovers of new industries" (Glaeser et al. 1992), which trigger innovations around core cluster activities, could influence such indirectly associated services as bioenergy production or waste treatment. The diversity and growth of networking activities are the key aspects for the development stage of cluster life cycle, which ensure its functioning and targeting (Menzel and Fornahl 2007; Brenner and Schlump 2011). This stage is associated with the rise of the profitability for the existing and start-up companies (Brenner and Schlump 2011), due to the developed and established infrastructure with multiple linkages, which accelerate the turnover rates.

The growth in any complex system results in a stable stage, which is characterized with realized potential of innovation activities, well-functioning connections between the elements. At the same time, it holds limitations in one type of the resources (social, environmental or economic). The expanding growth of cluster decreases (Brenner 2001) owing the need to cope with the scarcity of the limiting resource. The outsourcing of resource supply to the external elements of the system (other regions) stabilizes the system to a certain degree (to the point when externalization becomes inefficient). As cluster market activities reach certain equilibrium (Menzel and Fornahl 2007) existing companies continue to benefit from the location in cluster, but level of profit is lower than in expanding stage (Brenner and Schlump 2011). The innovation efficiency of the region decreases owing to the cooperation and increased concentration of the companies (Broekel et al. 2015). Later stages of cluster development might not affect the companies in considerable way and neither benefit the start-ups (Menzel et al. 2010; Frenken et al. 2015).

Complex system analysis indicates that at this stage complex systems reach the condition with highest potential critical mass of resources, which effects their transformation. In this condition the cluster could continue to functioning with a declining state (Hannigan et al. 2015), might go through the transformation stage in order to gain development continuum and transform in a cluster based on new spectrum of industries (Hassink 2005; Brenner and Schlump 2011) or reach destruction (Klepper 2010). One of the transformative forces for clusters is foreseen in their rearrangement to the needs of global value chains and gaining renewal through the reliance on the global supply and demand (Bailey et al. 2010; Sydow et al. 2010; Lazzeretti and Capone 2014).

Therefore, the development of agri-food clusters follows a complex system path, which demonstrates multiple reasons for cluster formation, development and destruction. In modern conditions of international trade they should not be separated from global food production flows and tendencies for bioeconomy activities. Such multilevel combined system creates additional challenges for the assessment and assurance of regional development trends in sustainable perspective.

1.3.3 Sustainable issues of "glocalized"of agri-food clusters

The formation of agri-food clusters is preconditioned due to the specific limitations posed to agri-food systems. Their dependence on the land resources made food production the single largest global land user and the biggest cause for deforestation (Gibbs et al. 2010; Fritsche et al. 2015; Nkonya et al. 2016). In order to overcome this limitation (together with natural abilities of soils to provide limited amounts of nutrients to plants) agri-food systems rely on intensification activities on existing lands, which is projected as a main path for agricultural systems (Alexandratos and Bruinsma 2012; Fritsche et al. 2015). Agri-food clusters rely not only on intensive and industrialized agriculture, but also on assurance of supply for outsources demand (market-oriented production), strong chemical industry support, intensive water and energy supplies, large capital investments, and functioning of specialized corporations with low labor intensity (Senauer and Venturini 2005; Simboli et al. 2015). Most of the supporting activities are impacting the environment in a high degree.

Despite multiple negative environmental consequences, caused by intensification of agri-food production (Tamásy 2013; Simboli et al. 2015), it is one of the main forces for agri-food cluster formation. And in opposite, agri-food clusters, playing an important role in the global economy, could be formed in rural areas of developing countries, involving a number of small and medium size enterprises with low technology development productions (Requier-Desjardins et al. 2003). However, the development of such clusters is limited as the actors are not able to further adapt more advanced technologies and evolve to the next level (Requier-Desjardins et al. 2003). Therefore, currently there is no other more sustainable alternative, which would provide similar rate of social and economic benefits (Tamásy 2013). It means that in the nearest future agri-food production should either increase the environmental safety of intensive production to support the beneficial cluster influence on the regional development or conceptually shift agri-food production via "sustainability transition" (Sutherland et al. 2014). There are multiple cases of technologies, policies and model adaptations which aim to achieve the first path (Tilman et al. 2002). It is recognized by the most agri-industrial companies that the production should aim for more social and environmental benefits (Fresco 2009; Notarnicola et al. 2012), and that is why they adopt minimization of resources use, material reuse and recycling, by-products and waste valorization and resources conservation (Koohafkan et al. 2012; Simboli et al. 2015). The development of the second path seems to be more complicated as the theory and methodology of its realization is currently "under conceptual construction" (Markard et al. 2012). This means that despite the ongoing adaptations and conceptual developments, agri-food production concentration will be based on intensive techniques. Even more, such concentration and increase of density of agricultural enterprises will pose certain risks for feed and food supply, for example due to extreme climate changes, soil degradation, water scarcity (Banse et al. 2014; IPCC 2014). This means that "glocalization" of agri-food production will come at expense of environmental resources and will not be a "free ride on sustainability" (Garnett et al. 2013; Buckwell et al. 2014; Loos et al. 2014; Fritsche et al. 2015; Gadanakis et al. 2015). It misses one of the main characteristics of resilient complex system – diversity of components (Hidalgo and Hausmann 2009; Asokan 2015), which could be brought in the future by the development of related bioeconomy activities such as biotechnology.

The lack of diversification in economic activities of industrial clusters is also highlighted as a thread for regional economy in cases of severe shocks of economy. Most authors imply that the presence of strong clusters in regions is beneficial, as such regions are less affected by rapid changes in economy (Enright 2003; Glaeser and Kerr 2009; Delgado et al. 2014). At the same time, due to the cluster specializations and in case the negative economic shocks are related to the main industry of the cluster, state of regional economy will be affected in a higher degree and with prolonged duration of the recession (Acemoglu et al. 2013; Delgado et al. 2014; Delgado et al. 2016).

Current trends towards diversification of regional development paths, dependent on agri-food clusters, include organic farming, animal-friendly production, environmental-friendly production and urban farming. Farming labeled as "bio" or "organic" as well as animal-friendly farming is aimed towards improving the quality of food product or quality of animal living (and food product as a consequence). On the other side, such trends neither benefit economy nor provide additional benefits to the environment (Tilman et al. 2002; Garnett et al. 2013; Tornaghi 2014). Environmental-friendly agri-food production is aiming towards reduced impact on the environment, while gaining economic and social benefits. In general terms this trend is the most related to the aims of sustainable development. However, compared to the rates of intensive agri-food production, environmental-friendly production is in minimal share, therefore is not currently serving as a viable alternative. Urban farming is becoming more and more popular taking into account extreme rates of urbanization (United Nations 2015b). The positioning of this trend as more sustainable alternative relies on the assumption that urban farming relies on already used lands for buildings (roofs, walls), decreased distances for transportation, fresh products consumption, community involvement and engagement in social activities, increase of local business opportunities in the cities (Fritsche et al. 2015). However, the environmental considerations still remain. At the same time urban farming is not a local industrial driver, which can play a role as an alternative to the intensive agri-food production rates. It is rather complementary with its possession of less than 5% of global food production (Fritsche et al. 2015). Moreover, the disappearance of agriculture from cities may play a positive role for their economic development (Findeisen and Suedekum 2008). The revision of the most popular agriculture diversification trends revealed their minor role in current economies and inability to perform a significant role of more sustainable alternatives.

Therefore, current conditions of "glocalization" of agri-food production trigger cluster formation in rural areas on the one hand and enhance the globalized distribution of goods on the other hand. That is why approaching multiple societal goals via the coupling of industrial cluster formation with transition to more sustainable systems (McCauley and Stephens 2012) will face numerous hurdles of socioeconomic or environmental nature.

Summing up the chapter, more sustainable development of regions should rely on balanced socioeconomic and environmental development model, which can function for generations with a high degree of assurance. The search for such development model requires the holistic assessment method for the estimation of interaction balance between complex components of regional system as agri-food clusters and international trade flows. Currently such assessment system is missing on the regional level.

1.4 The assessment methodologies of regional sustainability

The conceptualization of sustainability assessment at regional level sets specific requirements for the analysis and results. It should target the relative sustainability of performance with a clear concept and definition of sustainability as a societal goal based on a principle approach criteria (Pope et al. 2004). Currently there is no universal quantitative assessment methodology able to clarify the obstacles for regional sustainable development and identify solutions for the improvement. Three main groups of studies, oriented towards sustainability assessment, are applicable at regional scale. The first includes a multi-criteria approach, based on quantitative assessment of multiple indicators (Munda and Saisana 2011; Agostinho and Ortega 2012; Van Passel and Meul 2012; Singh et al. 2012; Kurka 2013; Cabello et al. 2014). Multiple criteria analyses are widely used for practical solutions of decision-making. At the same time such analyses require separate calculations of multiple indicators and further results. Even though multiple criteria analysis is a sound tool for integrated sustainability decision-making, it still has the disadvantages of separate benchmarking indicator systems, which cannot be combined into a single integrated unit. Moreover, results of multi-criteria assessments of two regions would result in hardly comparable profiles with results in multiple categories and decision-makers would face the problem of compromising in-between the values of various factors of sustainability.

Another group of indicators is connected with input-output table analysis (IOTA), known as a precise method for the identification of links for national and even global economies (Leontief 1951). Its application to regional economies allows to determine key industrial sectors (Midmore et al. 2006; Titze et al. 2011) and to perform a detailed economy analysis of regions (Jiang et al. 2010; Flegg and Tohmo 2011). Examples prove that the development of IOTA is an accurate system analysis method applied at regional scale. Regional application of IOTA allows indication of additional benefits for the assessment of regional development. Combination of monetized (economic) and physical IOTA at regional level results in analyses of waste generation and distribution (Jensen et al. 2011), ecosystem services determination (Patterson et al. 2010), and the determination of interdependencies between economy and physical resources tables (Hubacek and Giljum 2003; Suh 2004; Weisz and Duchin 2006; Hoekstra and van den Bergh 2006).

The third group of sustainability assessment systems is connected with the second, as it uses similar basic calculation apparatus. It is well-developed and connected with life cycle approach. Multiple assessment methods applicable to different scales from specific product (Life Cycle Assessment) to national and global levels (Extended Input-Output Life Cycle Assessment) are developed and successfully applied (Woodward 1997; Hendrickson et al. 2006; Finnveden et al. 2009; Guinée et al. 2011; Zamagni 2012). However, their application follows only separate pillars of sustainability, which is resulted in multiple works that promote life cycle techniques in combination with additional methodologies for a more integrated assessment (Tukker 2002; Jungbluth et al. 2011; Prado-Lopez et al. 2014; Ingwersen et al. 2014). Input-output analysis techniques associated with Life Cycle Assessment are of special interest on a regional scale as they are able to combine economic and environmental components (Hendrickson et al. 1998; Hendrickson et al. 2006), monetized and physical data (Hubacek and Giljum 2003; Suh 2004; Weisz and Duchin 2006; Hoekstra and van den Bergh 2006; Patterson et al. 2010). Further combination with social accounting matrix analyses (Allan et al. 2010) would allow for national and regional characterization based on economic indicators (with associated environmental and social data).

The need in management of sustainability (resources) caused the development of multiple sustainability evaluation approaches such as indicators, benchmarks, audits, indexes, accountings, assessments, appraisal, etc. Some of them are aimed for the global and national estimates (Environmental Sustainability Index, Happy Planet Index, Environment Vulnerability Index, Index of Sustainable Economic Welfare, Sustainable Governance Indicators, Sustainable Society Index, etc.), other are very specific technology and resource oriented (Life Cycle Assessment, Life Cycle Costing, Social Life Cycle Assessment). The use of the separate indicators at the regional level is quite limited (United Nations 2007). More integrated (LCA-based) assessment methodologies are also not oriented towards the sustainability estimation on regional level (Guinée et al. 2011). However, certain Life Cycle Approaches were applied for the national and regional levels. For example, EIOLCA quantifies the interrelationships among sectors of an economic system, enabling identification of direct and indirect economic inputs of purchases (Hendrickson et al. 2006). This concept was extended by including data about environmental and energy analysis from each sector to account for supply chain environmental implications of economic activity. It was used by US scholars for the combined evaluation of US and some other countries in 1995-2002. Therefore it has some disadvantages – it is not reliable anymore due to the timeframe and does not include the estimates for the social changes. However, the approach could be used as a basis for the regional level estimates.

Literature sources indicate the possibility of sustainability estimations for technologies or products via Life Cycle Sustainability Assessment (LCSA) which includes LCA, Life Cycle Costing Analysis (LCC) and newly developing Social LCA (SLCA) (Kloepffer 2008; Finkbeiner et al. 2010). LCA is a tool that can be used to evaluate the environmental load of a product, process, or activity throughout its life cycle. LCA is a standardized methodology both in Germany and internationally (ISO 14040, 2006; ISO 14044, 2006) and if the assessment follows them precisely it provides reliable results. LCC is a cost management method that considers the development of a product from the product idea to withdrawal from the market (product life cycle), i.e. from the “cradle to grave”. Numerous guidelines exist to support the successful implementation of LCC (DIN EN 2005; Verein Deutscher Ingenieure 2005; Verein Deutscher Ingenieure 2010). SLCA is the least developed analysis, which methodology is being formed (Kloepffer 2008; Finkbeiner et al. 2010). Despite the developed by UNEP Guidelines for SLCA of products (UNEP-SETAC 2009; Ciroth et al. 2011) the scientists meet the problems of databases absence, impact categories selection, qualitative and quantitative data incompatibility, lack of case studies and software absence. All above mentioned methods are time and resource consuming and require qualified experts for assessments. The LCA analysis itself might require a few months’ work for a specialist in order to provide proper evaluation of a single technology.

In order to deal with such “inconveniences” researchers and practitioners developed the streamlined techniques of evaluation. One of the most popular and widely used methods is the use of surrogate and proxy data included in databases and software, analogies and other approximate data (Weckenmann and Schwan 2001; Hochschorner and Finnveden 2003). It surely decreases the time spent for the analysis but utilizes an approach of using rather average data which holds significant mistakes in cases of specific application to regional conditions (Mutel 2012). In order to eliminate possible mistakes it has been proposed to perform the “underspecification” of surrogate data during the inventory analysis (Patanavanich 2011) or use the regionalized assessment methods and databases (Mutel 2012). One more widely used commercial approach is connected with the use of qualitative or semi-quantitative data, when the opinion of an expert or approximate data can decrease the time efforts dramatically (Bécaert and Bage 2006). Most researchers used and reviewed streamlined methods in LCA (especially with use of qualitative or semi-quantitative data) agrees that they are not reliable, unless the full Life Cycle Inventory (a stage of LCA) is completed (Hunt et al. 1998; Muñoz et al. 2006; Roches et al. 2010). At the same time, most authors also state that streamlined simplified reliable LCA is very needed (Yang and Song 2006; Ciroth et al. 2011; Pryshlakivsky and Searcy 2013).

Sustainability analysis of regional development poses additional challenges for the assessment techniques due to its dynamic nature and complexity of regional system. Even the estimation of a shift from one state of development to another is a challenging task and should involve, for example quantitative system modelling, socio-technical transition analysis and initiative-based learning. Such a bridging framework could provide "a basis for a more robust and complete analysis of sustainable transitions pathways that serves better to address questions and dilemmas faced by decision-makers and practitioners" (Turnheim et al. 2015), but even such a triple inclusion approach is leaving environmental and spatial qualities aside from the evaluation.

Despite multiple existing sustainability assessment methodologies there is a lack of approaches aimed at complex system view for the regional level. It is obvious that the methodology should account for the complete sustainability profile, but be flexible and adaptable for the use according to the conditions of different regions. Yet the assessment system should be transparent and reliable in regional comparison. As the specific requirements and possible solutions for such holistic system are not investigated, it is necessary to perform such analysis in order to indicate specific qualities of the assessment system, which would reflect regional differentiations and regional development trends.

1.5 Objectives and structure of the thesis

1.5.1 Goal and scope of the research

The main topic of the thesis is highlighted in multiple studies (Reed et al. 2006; Hacking and Guthrie 2008; Graymore et al. 2008; Graymore et al. 2010; Halog and Manik 2011) as a need to develop a holistic framework for the assessment of multiple issues of sustainable regional development, which could be applicable for the diversity of regional conditions and would provide a solid basis for the analysis of critical issues of sustainability transitions and would represent a fair comparison basis for the regional development strategies. The central objective of this thesis, therefore, is to provide a theoretical framework for regionalized sustainability assessment methodology and to identify a set of potential methods to implement the methodology. The specific objectives of this thesis are:

1. Identify the conceptual requirements of sustainability assessment at regional (subnational) scale corresponding to the Triple Bottom Line concept;
2. Review and identify existing methods, applicable for the identification and quantitative measurements of economic, social and environmental hurdles of regional development;
3. Develop an integrated methodology of sustainability assessment at regional scale, based on original proposed methods or combination of existing methodologies. This methodology should respond to the identified requirements of sustainability assessment at regional level;
4. Develop sustainability assessment methods aimed to assess the performance of separate actors within the scope of regional development. These methods should be applicable for the diverse variety of industrial sectors, social factors and environmental conditions, they should be inter and intra-comparable and complimentary with integrated regional methodology;
5. Develop an indicator of problematic areas of sustainable development ("hotspot analysis"), applicable within developed integrated regional sustainability assessment methodology;
6. Implement the developed integrated methodology to the Oldenburger Münsterland region as a case study and perform a comparative analysis with a region different in socioeconomic structure and environmental conditions. These case studies should identify the applicability of the developed methodology for the integrated regional sustainability assessment and comparative analysis of separate sustainability issues.

1.5.2 Structure of the thesis

The thesis is structured according to the logical flow of research project implementation. It starts with introduction, which includes the overview on the state of the art in scientific literature around the topic of the research. It is followed by the chapter aimed to conceptualize the development of research methodology. The detailed view and the analysis of the Regional Sustainability Development Methodology are presented after the conceptualization of the required methodology. Next chapters test the applicability of the proposed methodology for the assessment of sustainability of regional development in static and dynamic perspectives. The overall research is concluded with the final chapter, emphasizing on the value of the research for the science development and outlook for the future work (Figure 1.4).

Following structural approach was used for the thesis presentation:

- Chapter 1 provides an introduction to the topic area, including a review of “bioeconomy” and “sustainability” concepts’ relation to the food production and regionalization. The chapter also outlines the basic concepts of sustainability assessment at regional level. The objectives of the thesis are defined.
- Chapter 2 summarizes the main issues analyzed and main outcomes of the research presented in the published articles.
- Chapter 3 describes the conceptualization of sustainability assessment in regional perspective. It identifies main trends for the sustainability assessment of regions and main requirements for the regional sustainability assessment methodology. The conceptual model of Regional Sustainability Assessment Methodology (RSAM) is presented with the highlights of static and dynamic potential for its multi-level and multi-aspect application.
- Chapter 4 is the core of the thesis. It provides a quantitative methodology of regional sustainability assessment (RSAM), based on previously identified requirements (Chapter 2) for the sustainability assessment in regional perspective. The methodology includes the extension of Input-Output tables’ analysis to the socioeconomic and environmental spectrum of sustainability issues with further estimation of resource flows’ intensity and directions. It is finalized with an application procedure of RSAM testing with a case study for the static comparison of two regions of the same administrative level.
- Chapter 5 provides a specific case of RSAM application for the identification of agri-food clusters and their dynamic performance. The chapter includes series of static RSAM application to the three regions of the same administrative level (Vechta Landkreis, Cloppenburg Landkreis and Hochsauerlandkreis) in order to identify sustainability drivers and development trends in regional perspective. It outlines the potential of RSAM application for the agri-food clusters identification and regional dynamic performance.
- Chapter 6 gives a critical appraisal of the thesis. It presents comparisons of RSAM with other methodologies of sustainability assessment in regional perspective. Special

attention is paid to the concepts developed during the completion of the thesis. The practical relevance of the thesis is estimated with respect to current developments of regional databases and software development. The scientific relevance of the thesis is discussed with the outlook for the sustainability assessment in regional perspective.

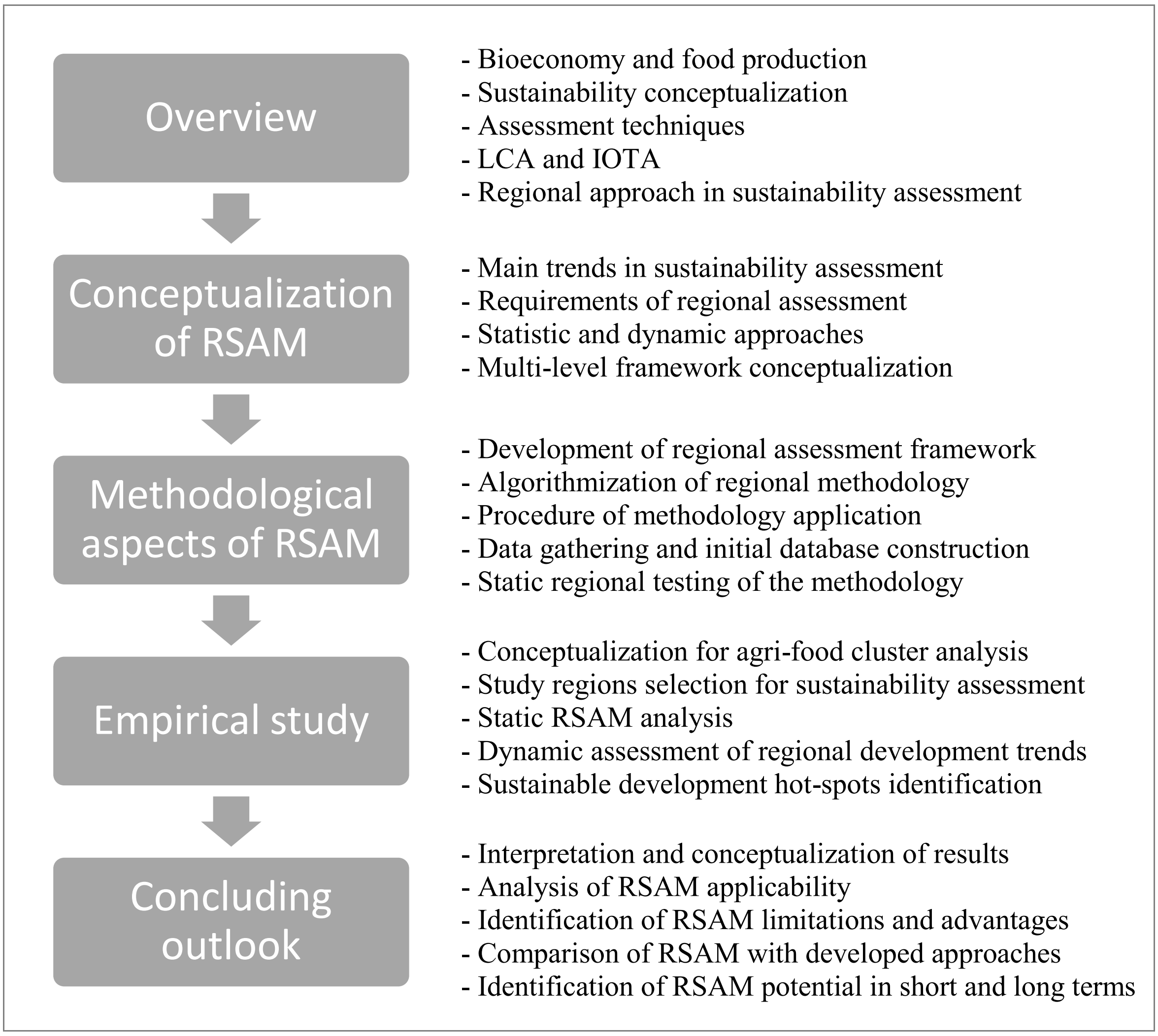

Figure 1.4: Structure of the thesis

2 Summary of publications

2 Summary of publications

2.1. Approach and structure of publications

This thesis has been prepared as a cumulative dissertation devoted to the establishment of holistic framework for the sustainability assessment of regional development. The idea of the sustainability assessment system creation on regional level was triggered by the need to holistically estimate the overall regional sustainability and relative weight of the different regional and global actors and processes. The development of regional sustainability assessment methodology became the overall framework, which unified different aspects reflected in the dissertation.

Another reason for the assessment methodology creation was connected with the fortification of bioeconomy as a “more sustainable” strategy of development. Such political term was connected to simple logic of more sustainable use of bio-based products instead of products based on fossils as raw materials. Many recent publications (Landeweerd et al. 2011; Sheppard et al. 2011; Richardson 2012; Nuss and Gardner 2013) illustrate conflicting examples to this idea. Therefore, bioeconomy oriented strategy of regional development should be holistically tested for the avoidance of indirect and rebound negative effects.

Bioeconomy and sustainability are two concepts, which correspond to the properties of complex systems. Moreover, they are highly interlinked and often equalized in publications. Indication of their relevance or separation required estimation of the level of their interaction which would be detailed enough to observe the annual changes in overall sustainability state. On the other hand the level of interplay should reflect the qualities of complex systems. Regional (subnational) level of sustainability assessment rather than local or national was identified as the one which corresponds to the both criteria. Therefore, the framework of sustainability assessment was constructed for the regional level with concentration on bioeconomy strategy of development.

In order to perform a sustainability analysis of regional development certain baseline criteria should be identified and accepted as a foundation for the holistic system development. Holistic sustainability assessment system should include analyses of multiple factors affecting regional systems performance and perceive to the regional development as a result of social (including economic) and environmental factors interaction. In order to reveal the interactions between different actors of the regional development the assessment methods concentrating on the analysis of connections between the components of complex systems were considered as a basis for regional sustainability assessment system development. The most sophisticated methods include those based on multicriteria analysis and life cycle thinking. Life Cycle Assessment (LCA) approach has benefits indicating the interconnections between various aspects of social and environmental interaction. In most cases it is used on local (product) level, but was applied as Input-Output table analysis for the national and regional levels. LCA-based IO table assessment approach was used in order to design and apply Regional Sustainability Assessment Methodology.

The specific need for the holistic assessment associated with environmental and social issues was recognized in the region of agri-food cluster (the Oldenburger Münsterland), which formulated the specific case study approach of the dissertation. Food production more than any other industry of sphere of social life is connected with the use of natural resources, transformation through the production and distribution chains, consumption at the consumer and waste utilization. Therefore, selection of food production as an indicative system for the assessment allowed interaction analysis between all the elements of the production and consumption chains within a region. Food is produced and consumed both regionally and globally, which allow indicating the connections of region with other regions. Therefore, food production and its impact on regional development (which should be well observed and identified in agri-food cluster) were selected as an indicative system for the regional system of sustainability assessment.

Above mentioned characteristics and approaches, studied in the research were structured according to the process of sustainability assessment framework conceptualization, development and application for regional studies. Three published and submitted original research articles followed the structure identified for the thesis. The first article deals with the identification of conceptual framework for the regional sustainability assessment. The main idea is the identification of the criteria and approach relevant to the sustainability assessment of regional development. Therefore, it first concentrated on the review of the existing concepts for sustainability assessment. Then, it performed an analysis of the needs for the regional sustainability assessment in static and dynamic perspectives. And the article was finalized with the theoretical conceptualization of regional sustainability assessment system construction. The article titled “Sustainability and regions: sustainability assessment in regional perspective” was published in 2015 in “Regional

Science Policy & Practice" (Volume 7, Issue 4, pages 163–186), which is an international peer-reviewed journal that publishes papers in applied regional science that explore policy and practice issues in regional and local development.

The second article deals with the theoretical model grounding for the regional sustainability assessment. It concentrated on the development of a sensitive method for the sustainability assessment. That is why the development of assessment system was concentrated on quantitative methodology, which can potentially reveal minor annual changes not only in overall state of development sustainability, but also in separate aspects of social or environmental interaction. With conceptually and theoretically grounded model the article continues on the static assessment of two sub-national level regions, characterized with diverse social, economic and environmental characteristics. The diversity of conditions was required to identify the sensitivity of the assessment methodology and its applicability for diverse regional conditions. The second article titled "Measuring Relative Sustainability of Regions Using Regional Sustainability Assessment Methodology" was published online in 2016 in "Geographical Analysis" (doi: 10.1111/gean.12102), which is an international peer-reviewed journal that publishes geographical theory, model building, and quantitative methods to geographers and scholars in a wide spectrum of related fields.

The third article, presented the finalized Regional Sustainability Assessment Methodology (RSAM) in case study application for the assessment of relative sustainability of agri-food cluster regions in comparison to a control region of the same level. It revealed the complete algorithm of RSAM application in dynamic perspective for the assessment of overall sustainability changes, hotspots identification and sustainability trends prediction. It also provided an insight on potential solutions, which might solve the development problems of the regions. The third article holding a strong applied aspect towards the characterization of agri-food cluster regions was submitted for the publication in "German Journal of Agricultural Economics" in 2016, aiming for the special section of cluster regions analysis. The journal publishes article both in German and English in the field of agricultural economics and related disciplines with wide audience of academic scientists, teaching staff and scientifically interested staff of public authorities, business and industry.

The author of the dissertation is the first author of all three papers. The coauthors contributed in all the paper similarly via the revision of the study conceptual design (Prof. C. Tamasy), provided consultation on drafting the manuscript (Prof. A. Mathys) and critical revision for intellectual content (Prof. C. Tamasy, Prof. A. Mathys and Dr. V. Heinz). The author of the thesis contributed in most degree via the studies concept design and theory development, acquisition of the data for the sustainability analyses, analysis and interpretation of the data, drafting of the manuscripts and papers' revisions. All the articles were submitted after final approval of all the authors for the publishing.

2.2. Summary and results

The assessment of sustainability of regional development has been an essential topic in geographic research literature for a more than two decades (Harris 1996; Graymore et al. 2010; Wang et al. 2016). The author of the dissertation agreed with the scientific literature (Graymore et al. 2008; Mutel 2012; Hellweg and Milà i Canals 2014) and recognized the assessment of sustainability of regional interactions as a core field able to provide the insight on the "optimal" connections to the global food networks and local production sites. Despite a progression in terms of regional assessment of various sustainability aspects, currently there is no universal sustainability assessment methodology, which would be applicable by the actors of agri-food supply chains interactions (policy makers, regional planers, agri-food business and scholars). Moreover, the lack or misinterpretation of sustainability objectives due to the availability of a wide range of "sustainability" definitions is reflected in a wide range of studies aimed to provide the estimates of "sustainability" without a clear holistic conceptual identification. That is why the first article was aimed for the conceptualization and theoretical development of the holistic sustainability assessment system, which would correspond to the needs of policy-makers for identification of regional development paths, policies' effectiveness and potential changes to sustainable development of regions. This approach was identified as the most relevant due to the need of policy-makers for the holistic vision of development trends of regions and their sustainability.

The article representing a first part of the dissertation research initially reviewed the best up-to-date practices for sustainability assessment revealed in scientific literature and models of sustainability assessment (including both qualitative and quantitative). The revision allowed the identification of the main concepts of other researchers, set as a basis for the construction sustainability assessment systems. Alongside with the identification of existing trends for the sustainability assessment the needs for regional level of sustainability assessment were determined. Due to the complexity of regional development dependencies the authors identified five main criteria for the regional sustainability assessment:

(1) A region was identified as a complex interaction system, which remains in a dynamic state due to the elements interaction in the system and with other systems (regions, local objects and global level). We argued that only holistic vision of a region as a complex system would allow for realistic representation of the sustainability state. The acceptance of a region as a complex system allowed for allocation of its interaction abilities with different hierarchical levels (local, national and global).

(2) Sustainability assessment system at the regional level should be holistic in order to reveal the wide spectrum of regional system interactions and their qualities. In sustainability assessment the holistic approach is connected with the unification of assessment categories via Triple Bottom Line (TBL) approach. The author of the thesis followed this approach as it allowed for effective grouping of diverse sustainability relevant factors into three main categories. TBL concept was used as a grouping framework, rather than the main approach, reflecting the interactions between the elements of the complex regional system.

(3) The connections between main regional actors were identified as resources flows, therefore the overall transfers of natural, social and economic resources could be captured with the resource capital approach. It required the estimation of the amount of resources in the stock and the dynamics of the stock changes. Specific criterion identified as important for sustainability assessment was the analysis of different resources types (social, economic, environmental) interaction within the regions, which identified its abilities for self-sufficiency with interregional "weak sustainability" (ability to supply own needs with in one resource with other types of resources). The need to reveal inner regional and outer regional resources interactions led to the identification of Input-Output Analysis as a main approach for the regional sustainability assessment system.

(4) The analysis of sustainability assessment needs at the regional level called for the introduction of a specific measure of inner resources cycling flows into the Regional Sustainability Assessment Methodology (RSAM). This specific measure allowed the estimation of the "length" of resources cycling within the inner-regional network, which reflected on the efficiency of the resources use. This measure was aimed to separate the

regions depending on the inner resources (with high self-sufficiency) and those depending on the external resources flows (with high "weak sustainability").

(5) The representation of sustainability state at a specific period of time was identified as an important issue, but the one which was not reflecting regional vulnerability to "lock-in" in development and potential of dynamic changes. That is why RSAM included static and dynamic aspects of regional sustainability assessment.

The predefined conceptual considerations for sustainability assessment at regional level allowed further theorization and development of Regional Sustainability Assessment Methodology, which was performed in *second published article*. It pointed out at the need to distance from the sustainability assessment techniques based on qualitative expert opinions as those, which hold the qualities of subjective evaluation and impreciseness. Moreover, such approach is criticized for the considerable requirements in terms of time and often money. In controversy to such trends our approach was concentrated on the accounting of relative regional sustainability as a function of internal and external resources flows. We argued that sustainability of regional development can be accounted as a result of resources capitalization and interchangeability.

The article further concentrates on the development of mathematical and logarithmic approach for the regional sustainability assessment. Similarly to the general Life Cycle Assessment approach it included four main components. First (1) statistic data was acquired and gathered from publically available regional sources. Next (2), the Input-Output Table Analysis (IOTA) was performed with the original data for the specific categories of sustainability (e.g. producers economic activities, social support, biotic resources). IOTA was performed both for initial data and for monetized data. In order to monetize the data RSAM relied on real regional prices for the resources (salaries, prices for the lands etc.), which is different from commonly used approach of using averaged national data (Lahr 1993; Miller and Blair 2009). Further (3), IOTA was performed for the integrated monetized matrix, which allowed the overall representation of relative sustainability state of the region. Simultaneously with the last two stages (2) and (3) the analysis included the estimation of cycling resources flows within separate categories and overall integrated regional scale with adapted cycling indexes (Allesina and Ulanowicz 2004; Ulanowicz 2004). The last stage of the static sustainability analysis with RSAM (4) included interpretation of results.

The conceptualization and theoretical model development of RSAM allowed first demonstrating application for the model regions of Vechta (Vechta Landkreis, Lower Saxony, Germany) and Hochsauerlandkreis (North Rhine-Westphalia, Germany) in 2010. Both regions are located in northwest part of the Germany, but are diverse in terms of economic development, core industries, geomorphological and geological conditions, population density etc. The main idea of a brief study was the identification of comparative potential of RSAM for the diverse regional units of the same level. It was demonstrated that Vechta Landkreis had a lower holding capacity of resources in the activities of the region than Hochsauerlandkreis. At the same time, Vechta Landkreis was more dependent on the connections with other regions ("weak sustainability"), while Hochsauerlandkreis relied more on inner resources (especially relevant for land and biotic resources). Therefore, it was demonstrated that use of RSAM indicated Hochsauerlandkreis as a region with stronger relative sustainability (higher rate of reliance on inner resources). Vechta Landkreis was indicated as a region with relatively "weak sustainability" due to its higher dependence on external resources. It was indicated that the dependency on external resources should be lowered, while maintaining the same level of economic activities possibly through diversification of economic resources flows. Moreover, it was indicated that for Vechta Landkreis the high dependency on external biotic resources in core economic area would hold risks of rapid crisis in case the external supply was affected by global tendencies.

Application of RSAM for the separate categories also identified the resources flows of relatively low importance, which act as limiting factor for the regional system development. The activation of the regional development could be done via the increase of relative value of the limitation flows (e.g. through subsidies, investments, tax deductions, etc.). Another effective meaning to cope with the high dependency on the external flows is their diversification. Such example actions could be performed by the regional planners and policy makers to improve the overall development of regions.

Despite overall efficient performance of RSAM for the static comparison of relative sustainability state of regional development certain drawbacks were pointed out. RSAM is a methodology which provides relative comparison units. In order to execute a meaningful analysis of regional sustainability it is always needed to take two regions into consideration. In other cases relative nature of results can be useful for the inner regional analysis of the results for the estimation of sustainability hotspots and dependency on the external versus internal resource flows. As shown it can also provide a feedback on the sustainability optimization strategy for a region.

Another limitation of RSAM use is its dependency on the quantity and quality of the data. Even though it was constructed on open statistical data the issue of Life Cycle Assessment and IOTA approached dependency on data remain. For example, the static analysis of the regions in the second article was predetermined with the high availability of data from a single source. Single source data use called for the elimination of potential inconsistencies in approaches for data gathering and calculation. Furthermore, it is perceived that RSAM would be the most effectively applied by the regional policy and planning agencies having access to the wide spectrum of regional data. It will assure its automation and reliability.

The third article, included in the scope of dissertation, concentrated on the dynamic relative sustainability assessment of three sub-national regions of the same level. Two regions (Vechta Landkreis and Cloppenburg Landkreis, Lower Saxony, Germany) had similar historic and economic background. Historically they composed the Oldenburger Münsterland, which functioned as a single region. Later the region was divided by administrative border, but established socioeconomic connections allowed the regions to function as a single agri-food cluster. Selecting these regions for the case study the research followed the dual task. First, RSAM should be tested on very socioeconomically and environmentally similar neighboring regions. Sustainability analysis with RSAM allowed identification of similarities and variations in terms of sustainability of development. Second, the research aimed for the analysis of regional agri-business cluster development. That is why it included static and dynamic assessments. The third region (Hochsauerlandkreis, North Rhine-Westphalia, Germany) was included in the case study as a control region. This was the research was aimed to identify the characteristics of agri-food cluster functioning, limitations of development and risks for the sustainable development.

The empirical study was based on the data for the period of five years (2008-2012) and revealed the importance of resources cycling in regions, identification of dependency on external resources and self-sufficiency as indicators of regional sustainability (social, economic and environmental resources use efficiency) in a dynamic perspective, applicable to diverse regions and separate aspects of sustainability. The application of RSAM was based on the first published conceptual article and followed the methodological approach developed in the second published article.

The study demonstrated that application of RSAM to socioeconomically similar regions have comparable indices of endogenous recourse cycling, dependencies on external resources and self-sufficiency. Hochsauerlandkreis had different results for the period of 2008-2012. While the results themselves were quite expected (higher dependency on the external resources flows especially for the biotic resources for the agri-food cluster regions) the potential of RSAM use for the agri-food clusters identification was highlighted for the first time. However, it should be noted that the study did not aim for such an outcome and does not have significant results to fully ground such conclusion. The potential of RSAM application for the cluster regions identification should be further investigated with a wider range of industrial clusters.

The analysis of interregional performance demonstrated that RSAM could provide comparative results on the rate of economic activities if producers' activities are analyzed. Thus, the analysis revealed that the regions of the agri-food cluster had almost the double rate of economic resources cycling within regions, comparing to the control region. Similarly agri-food cluster regions were characterized with higher rates of economic resources self-sufficiency. It should be mentioned, that high rates of economic resources cycling in the regions were supplied in a great degree by the external resources flows (not only economic). Such dependency on external resource flows contains a risk of economic efficiency decline in case of severe crisis activities associated with the use of external resources.

The analysis of biotic resources (as a basis for agri-food functioning) confirmed the high dependency of agri-food cluster regions on external resource flows (which corresponded to the previous conclusions for the static analysis of 2010). In dynamic perspective the stable nature of difference in main indices of RSAM (dependency on external resource flows, rate of resources cycling in the region, self-sufficiency rate) for the various regions was confirmed. Therefore, the analysis of separate selected categories of resources with RSAM indicated its potential for the detailed dynamic analysis, which can provide the results on the identification of sustainability hotspots.

At the same time, aggregation of separate categories into "sustainability pillars" (social, economic and environmental) with further RSAM analysis did not indicate the specific drivers of agri-business cluster formation or hotspots at the regional scale. Such results could be explained with the limited amount of resource categories included in the study.

Further expansion of categories profile might improve the reliability of RSAM usage for the "sustainability pillars" analysis and aggregated hotspots identification.

The application of RSAM revealed varying rates of resource use efficiency, self-sufficiency and dependency on external resources for both static and dynamic perspectives. The dynamic analysis indicated stable relative rates of results for the indices included in RSAM. The study also included the trial for the forecasting trend identification based on the changes of resources use for the five-year period. It forecasted minor potential decrease for the cycling rates of inner resources cycling and the self-sufficiency rates accordingly for all the three regions without considerable variations in the results in-between the regions. Further analysis indicated that the dependency of the regions on the external resource flows most probably will not change in a meaningful degree. Taking into account the predicted reduction of inner cycling rates the meaning of the external resource flows would increase. While for the control region such minor change would not cause severe problems, the changes might affect the performance of the agri-food regions in a negative way increasing the risks associated with the external resource supplies.

A single approach applied to the dissertation resulted in the production of three original research articles which represent a sequence of typical research. The first article concentrated on a conceptual approach, which served the basis for the theorization of methodological system in the second article and application of the developed methodology for the case study in the third article. This way, every article is interlinked with the other ones and present a separate pieces of a single research aimed for the regional sustainability assessment based on Life Cycle Assessment approach with specifics of agri-food regions analysis. Scientifically, the research added a new methodological approach to the sustainability assessment of regional development, based on a new combination of existing research methods but applied in a new way for the assessment of complex regional system. A number of new analytical approaches were applied for the data analysis, combination of data of various nature, regional self-sufficiency estimation and regional activities in separate categories (agri-food production) analysis. Regional Sustainability Assessment Methodology is a complete assessment framework and can be applicable for relative regional sustainability analysis but requires further testing with a wider regional reach in different world regions and conditions.

3 Sustainability and regions: sustainability assessment in regional perspective

This chapter was published and can be accessed in the following peer reviewed publication:

Smetana S, Tamásy C, Mathys A, Heinz V (2015) Sustainability and regions: sustainability assessment in regional perspective. Reg Sci Policy Pract 7:163–186. doi: 10.1111/rsp3.12068

4 Measuring relative sustainability of regions using Regional Sustainability Assessment Methodology

This chapter was published and can be accessed in the following peer reviewed publication:

Smetana S, Tamásy C, Mathys A, Heinz V (2016) Measuring relative sustainability of regions using Regional Sustainability Assessment Methodology. Geographical Analysis. doi: 10.1111/gean.12102

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5 Sustainability assessment of agri-food clusters: a case study based on Regional Sustainability Assessment Methodology

This chapter was submitted for the publication:
Smetana S, Tamásy C, Mathys A, Heinz V (2016) Sustainability assessment of agri-food clusters: a case study based on Regional Sustainability Assessment Methodology. German Journal of Agricultural Economics. Submitted article.

6 Conclusions and outlook

6 Conclusions and outlook

6.1. Development trends of regional sustainability concepts

This dissertation research performed during the three-year period dealt with the number of conceptual issues, which had to be connected and clarified in order to achieve the main aim of the thesis. Two concepts have an especially wide scope and fuzzy interpretation among all the discussed and theorized notions. “Bioeconomy” and “sustainability” outlined the grounding for the research approach set in the thesis. They are quite often conceptualized as similar interlinked concepts, as one leads to the other and the other requires the first one for the realization. Theoretically, it might sounds reasonable and logical, but on practice multiple examples, especially on local and regional level indicate that it is too early to equalize the concepts, partially because of their unfinished conceptual evolution, partially because of the various targets and, not in the last turn, due to the differences in the scopes. However, there are a lot of similarities between them as well. Bioeconomy and sustainability are both (in their modern meaning) originated in the policy development, when there was a need to outline the shift towards the development approach away from “business as usual” to more efficient cases. With time the concepts transferred to the other aspects of geographic, social, economic and environmental research mostly because of a wide reach of the concepts. Every field of sciences added new qualities and characteristics to the concepts, which resulted in the creation of thousands of definitions.

In order to cope with the hurdle our research concentrated on the regional scope, as it promised to be the most appropriate level to deal with the complex concepts and definitions of bioeconomy and sustainability. Regional (subnational) approach included the characteristics of global complex system interactions and local specification of the data. Such a combination allowed preserving the complexity of the assessment approach and the use of detailed specific data to increase reliability and credibility. Regional scope of sustainability and bioeconomy interactions resulted in the need of specific criteria for the analysis.

Scaling down the concept of bioeconomy from global and national level to regional resulted in the identification of agri-food production and forestry as the main drivers for the economic development based on biomass products. These traditional sectors play a significantly greater role than the production of bioplastics or biofuels. Agri-food systems traditionally represent an important part of socioeconomic and environmental development in the regions. Moreover, agri-food production often plays an important role for the creation of "industrial clusters" in rural regions, which increase their potential for the innovation and economic success. Regions, traditionally oriented towards agri-food production, are largely affected by the acceptance of the bioeconomy strategy of development. Bioeconomy strategy forces farmers and regional food producers to allocate capital (social, economic and natural) to the need of substitution of fossil fuel goods with biomass based products. Biogas and bioenergy are the most popular products, which entered the market and started competing with agri-food systems for natural resources.

Agri-food production chains are among the most studied subjects in multiple disciplines, yet they are complex systems, which include multiple sub-systems (e.g. agriculture, communities, capital, and resources). The complexity of agri-food systems in regional perspective is as well caused by the impact from higher (global) and lower (local) hierarchical levels. They also include specific interactions with natural systems (competition for the resources), bio-based fuels and energy (competition for the resources) and communities (complex interactions). In order to interpret such a regional system and find more sustainable solutions for the development, a holistic and multilevel assessment framework is needed. That is why *the main objective of this thesis was to develop a theoretical framework for regionalized sustainability assessment methodology, which could indicate the relative level of sustainability of regional development and provide an insight on the development paths for the agri-food regions*. The implementation of the developed methodology was identified as a sub-main objective. To achieve these goals, three concepts were considered as a basis for the methodology creation. The first concept argued that regional sustainability is a state of regional development which supports balanced socioeconomic and environmental development model paths functioning for generations. The second concept identified sub-national regions as complex systems, with all the appropriate properties and the nonlinear character of elements' interaction. The third concept perceived main components of the complex regional system as various resources of environmental and social (including economic) nature. The reliance on the three mentioned conceptual approaches allowed setting of specific tasks to the methodology of regional sustainability assessment.

The completion of the thesis research took around three years. There were quite a few developments in scientific literature connected with different aspects of the study during this period. Most of them were highlighted and outlined in the discussion parts of the dissertation, but the recent ones were not included. In order to cover this gap and outline the main tendencies connected with the regional sustainability assessment a brief overview of latest literature is included in a few following paragraphs. Recent studies are reviewed from the view of their connection to the main concepts and objectives of the study.

We used price index (real regional prices) for the goods and services in RSAM as a unifying monetized unit, which has certain advantages and disadvantages. Even though the monetization approach is known for a long time there are some studies reviewing the use of price or other economic allocation approaches as a method for unification (Cristóbal et al. 2016). It is still quite unclear how other unified metrics can be used for the social aspects. However, Jones and Monsivais (2016) reflected on the potential use of economic versus energy related metric units and gave benefits to the use of energy as the most appropriate metric for the assessment of public health and healthy diets. Quite interesting are the developments towards the application of "emergy" as an assessment unit (Kamp et al. 2016; Nakajima and Ortega 2016; Baral et al. 2016; Yu et al. 2016a). Both units are not new and indicated studies do not solve the limitations which would allow their operation as universal units of sustainable interactions measurements. Available literature, neither reveals on the possibility of resource approach for the integrated assessment of regional development sustainability nor provides any examples on the use of cycling indices for the efficiency of flows estimation. However, certain trends towards a combination of assessment units with resource use are identified (Nakajima and Ortega 2016).

RSAM is based on the use of Life Cycle approach methods which were identified as the most promising to review on the connections between different categories of regional development. Current trends towards improvements of Input-Output Life Cycle models and Fuzzy Data Envelopment Analysis framework for eco-efficiency assessment (Egilmez et al. 2016) support the statement of IOTA application potential. Scientific literature emphasizes on a few relevant to regional sustainable development issues. The overall tendency towards regional assessment is progressing in LCA studies (Yang and Heijungs 2016). Certain attention is also devoted towards the needs to reveal the connections between regions as elements of networks. For example, a concept of megaregions (interlinked clusters of prime economic importance) concentrates not only on networking nodes, but also on the ties between the nodes of production networks (Ross et al. 2016). It draws attention to the functional relations, which correlates with the resource flow approach of this thesis. But even though the authors of the article (Ross et al. 2016) identified a functional concept of the sub-national regions functioning and found some connections for the regional sustainable improvement (disparities, governance, collaboration, planning, etc.) they did not indicate any approach for the sustainability assessment. Some literature further concentrated on the development of new assessment methods such as Sustainable Development Index as an averaged sum of multiple statistically normalized factors of social, economic and environmental relevance (Kwatra et al. 2016). While this indicator includes statistic normalization of each factor, it does not provide the relevant weighting of various factors; therefore they all are holding equal value for the sustainable development. The relevance of such factor to the reality is doubtful. However, the authors applied another method for the correlation identification between various factors relevant to the sustainable development of regions (Kwatra et al. 2016). The application of the correlation analysis in RSAM matrices (instead of real data use) might decrease time investments of practitioners without compromising the accuracy.

Another group of authors developed a novel regional sustainable development assessment method and framework based on sustainable development level, sustainability of regional development and system coordination through the methods of nonlinear principal component analysis and Gram Schmidt orthogonalization (Tan and Lu 2016). Their framework methodology is using traditional commutative methods in a novel way, which allows for the advanced dynamic and predictive assessment of complex sustainable issues. At the same time it holds challenges for the interpretation of results: it is not clear how an investigator can apply the framework to identify the areas of improvement. Further development of this methodology might provide valuable results.

This dissertation study approach followed the path for using a holistic system for the assessment of regional sustainability in bioeconomy perspective. Such a decision was dictated by the need to get quantified analytical and reliable results. At the same time, literature studies continue the search of simplified and streamlined approach for the Life Cycle analyses. For example, some authors proposed assessment of only separate stages of supply chains (Pernollet et al. 2016), or introduction of key performance indicators (Ramos et al. 2016). In controversy, further complication of assessment systems through various combinations of existing and novel methods is observed (Albers 2015; Yu et al. 2016b; Kamp et al. 2016; Onat et al. 2016). Current trends of sustainability assessment techniques dealing with agri-food systems continue highlighting the need for more sophisticated, holistic and comprehensive assessment methods due to the complexity of food systems (Notarnicola et al. 2016). Therefore, there is no solid evidence that the objectives set and achieved in the dissertation were solved by other research.

Current trends of research in literature associated with sustainability assessment of regional development are still not able to cover the gap in science identified prior to the completion of the dissertation research. There is still a problem of existing sustainability assessment techniques not allowing for a precise and integrated analysis, which could be applied by policy-makers, regional planners and researchers for identification of regional development paths, policies effectiveness and potential changes to sustainable development of regions. Yet the conceptualization and theoretical development of Regional Sustainability Assessment Methodology supported by case studies is the first step to cover the lack of regional sustainability assessment framework. A few identified above studies aim for integration of assessment techniques, which makes them complex and complicated for the interpretation and sets certain difficulties for the replication. Others follow a path of simplification, which reduces the reliability of results. The most crucial research trend is dealing with the need to assess the connections between the elements of the complex system. The insight on the connections between elements of the regional system, including social, economic and environmental factors can reflect the importance of resources interchangeability ("weak sustainability") in regional development. Therefore, the ability of RSAM to analyze intensified linkages of diverse levels and qualities has a potential as an effective regional assessment technique.

6.2. Methodological developments

Despite many other approaches for the sustainability assessment at regional level, RSAM conceptualizes on the evaluation of social, economic and environmental capital as a basis for the analysis. Moreover, different types of capital reviewed both as a storage and as a dynamic system with multiple connections between different types of the resources and between different hierarchical levels. This way the capital approach in RSAM requires identification of resources amounts, their change and degradation. The estimation of resource abilities for the exchange and substitution ("weak sustainability") was one of the main hurdles and one of the strongest components of the assessment system (RSAM).

Resource exchangeability and substitution in RSAM were modeled with IO matrix analysis and assessment of resources cycling in the regions. In order to cover the TBL aspect of sustainability assessment adapted and extended IO table analysis approach was combined with social aspects to identify the connections between diverse types of resources. Utilization of extended economic-social LCA in our conceptual approach revealed the possibility to reflect the amount and the state of resources and their interconnections. The construction and analysis of extended socioeconomic and environmental regional IO tables provided the results on the static state of the resources. Theoretically, two different regions might have a similar relative IO table profile, but their development would be different due to variation in inner and external cycles. In order to evaluate the cycling rates of resource flows in systems, this thesis relied on analysis of cycling connections of complex systems. It indicated the number and "length" of inner cycling connections between resources. The amount of resources cycling in the system provided a relative estimation of regional development maturity level.

The analysis of interactions between different resources in regions also reveals their abilities for the self-sufficiency. Self-sufficiency index (original measure) is identified as a sum of IO table minors (ability of a system to supply itself with own resources). Alternatively to the assessment of cycling resources, self-sufficiency analysis includes "passive" or stored resources. The comparison of inner resources involved in regional activities with the amount of resources engaged in external exchange indicated the dependency of a region on external sources. Therefore, combining extended economic and social input-output LCA approaches with analysis of resources cycling between main sectors and actors which affect regional development, provided information on the state of regional development, the problem areas, the main actors of regional development system, system dependency on external resources, etc.

Despite the ability of conceptual multisystem analysis and multipurpose applicability of Regional Sustainability Assessment Methodology (RSAM) a number of specific challenges were solved before it was claimed to be an effective and practically applicable methodology for the regional sustainability assessment. First, RSAM required sophisticated mathematic and methodological apparatus. That is why the second part of the thesis was devoted to the theoretical development of calculation algorithms and mathematical models. For its development the research partially relied on the methodologies, presented in literature, but the issues of different approaches combination and adaptation to the regional conditions were the main focus.

This dissertation developed a methodology for the assessment of sustainability of regional development. RSAM increases the ability of LCA and IOTA methods to reflect the differentiation of regional development in the combined form of socioeconomic and environmental properties. The application of RSAM requires complex model analysis with requirements for the extensive data. It was identified that RSAM should be based on the use of specific regional data for the "regionalization" of the methodology. In this manner the need for the search of regionalization indices or coefficients to scale down national or global data was eliminated. RSAM demands complete regional statistical databases and modification of the core IO tables accordingly to the available data. Although there are regional statistical databases available to the public, they have certain limitations in terms of integrity and age. That is why it will take considerable work before RSAM could be applied globally to the great variety of regional conditions and would be supported with relevant data. Developed and tested RSAM has a number of assessed categories in the spectrum of TBL and three basic core concepts of the thesis, though not all sustainability relevant categories that could be a part of RSAM are currently covered. Until the sufficient data are available to cover the missing categories, RSAM will probably be used as a scientific methodology for the assessment of separate case studies rather than routinely to assess the sustainability of regional development by regional planners and policy-makers.

There are several approaches of sustainability assessment, which have different degree of relevance to the presented RSAM. The first approach, which is the most used one in the current state of the art, relies on the use of indices and assessment of separate "hot points" of sustainability, such as carbon footprint, animal welfare or return on investment, etc. The advantage of such approaches is that they have comparatively easy access to the data needed and can be performed relatively fast. Most of such tools are available for the use by the public, but their reliability is vague.

This dissertation provides a theoretical basis for RSAM approach, which can be used at any regional level with the application of freely available statistic data, but with a comparatively higher degree of complexity assurance and a holistic approach. It was calculated that static sustainability assessment of one region presented in the thesis required the input of a few thousand data points. Because RSAM is a relative comparison methodology the meaningful (comparative) regional sustainability assessment would require the input of ten thousand data points for each year of comparison. The overall, in order to estimate dynamic regional sustainability of the three regions presented in the thesis the input of 150 thousand data points was needed. Therefore, RSAM at its current state is not intended for the simplistic application by non-trained practitioner. However, the more complete data availability will promote the use and application of RSAM. One of the conditions of its further use is connected with digitalization and automation of calculations, which can reduce the time for the calculations, which in modern conditions of software development is not a complicated problem.

Another approach, related to RSAM is the use of integrated assessment techniques, most of which are based on multi-criteria analysis. For example, regional sustainability assessment, based on multi-criteria and sensitivity analysis applied to Spanish and Mediterranean regions allowed to rank regional performance with a composite indicator which weighted and summed up the performance of the regions in multiple categories (Munda and Saisana 2011). Despite the wide potential coverage of sustainability indicators, the use of multi-criteria approach is limited due to the difficulties of comparison results interpretation. Multi-criteria assessments also lack the ability of results unification for the single score representation and lower hierarchical level analysis with a single system. In order to exclude this limitation RSAM uses variables unification through real regional prices monetization. After transformation of all the data into single units it is possible to apply different techniques of calculation and data combination. Such approach, similar to IOTA, allowed for the multiple combination possibilities and assessment of the elements' interaction. Such indication was important to distinguish the interlinkages between various resources in the regions. Further analysis of resource connections and their weight, as well as their cycling inside and outside of regions set the basis for static and dynamic analysis of relative regional performance.

The application of techniques included in RSAM is not novel in science. IOTA was first presented in 1951 and allowed Wassily Leontief to earn a Nobel Prize in Economics (in 1973). Since then IOTA was adapted, modernized and applied to the multiple problems of economics, environmental management and social welfare. Moreover, there were a few successful trials of economic and environmental or economic and social data combination, but the triple combination with the use of IOTA is not known to be performed. RSAM included a novel approach of social and environmental data accounting through absolute values and transformed by the application of regional monetization (real price index). Such method is different from more traditional approaches of using Regional Purchases Coefficients or Regional Adjustment Surveys (Lahr 1993; Miller and Blair 2009). Moreover, the models were initially created with regional data and therefore did not require additional regionalization as it was done in many regional IO studies, when regional data were approximated from national.

The combination of various data through real regional prices monetization and further input-output matrix construction allowed to overcome the main hurdle of progression for today's Life Cycle Assessment approach. It has the problem of social data combination with integrated environmental Life Cycle Assessment and economic Life Cycle Costing. The integrated sustainability assessment (Life Cycle Sustainability Assessment) is currently under construction (Guinée 2016). This research considered the difficulties of assessing the social aspects of product level interactions and concentrated on more aggregated regional level. Regional level application of Life Cycle approach is interlinked with IOTA, as they both are based on similar calculation basis. It allowed, using the concept of Life Cycle Thinking, integrate social, environmental and economic aspects of production and utilization chains into the single assessable system.

The modelling of an integrated assessment system based on IOTA provided only the overview of the direction and the number of resource flows. Without additional measures the assessment system would not be capable of relevant information analysis. Therefore RSAM included specific indices and measures. The accounting for the amount of resources cycling in the system was first introduced in the field of ecology for the complex ecosystem interactions analysis (Allesina and Ulanowicz 2004; Ulanowicz 2004). Somewhat similar techniques were applied in order to account for urban metabolism interactions with main focus on economic activities (Zhang et al. 2014b). However, these approaches were never applied for the complex and holistic sustainability assessment of regional development. The indices (Han, Finn and Comprehensive Cycling Index) of resources cycling in a balanced regional model allowed the indication of inner and outer dependencies on the resource flows and also an estimation of self-sufficiency (as a sum of multiple combination options of resource supply) of the regions. There was no indication of resource cycling rates estimation applied in RSAM to economic, social and environmental resources found in the literature up to date.

6.3. Lessons learned from case studies

In order to test the functioning of RSAM two subnational regions were first compared with a static sustainability assessment approach for 2010. The comparison indicated that Region (V) (Vechta Landkreis, Lower Saxony, Germany) had a lower holding capacity of resources in the activities of the region than Region (H) (Hochsauerlandkreis, North Rhine-Westphalia, Germany). At the same time, Vechta Landkreis was more dependent on the connections with other regions ("weak sustainability"), while Hochsauerlandkreis relied more on the resources that were available in the region. It is especially evident for land and biotic resources. Input-output tables' analysis for producers also indicated a similar trend of their dependency on external resources in Vechta Landkreis. Therefore, the static analysis characterized Hochsauerlandkreis as a region with stronger sustainability (stronger reliance on inner resources), and Vechta Landkreis as a region with weaker sustainability (a higher dependency on external resource flows).

The high inflows of the natural resources from other regions and high outflow rates determined Region (V) as "external resources transformer". It resulted in the situation when external raw resources (including human capital) were changed into other economic goods and supplied back to the external regions. The added value remained in Region (V) system (high rates of resources cycling for producers were indicated). This situation triggered minor attention to the quality of human resources (availability from external systems) and increased impact on the environment via waste flows.

The detailed analysis of some resource transfer flows indicated a reliance of Region (H) on its own biotic resources, while Region (V) was highly dependent on the resources from other regions. Such dependency on external resources should be lowered, while maintaining the same level of economic activities. This could be done through diversification of economic activities with the support from the regional policy makers and planners. The application of RSAM for the analysis of separate resource transfer flows could identify those with lower relative importance. A higher attention should be paid to low relative importance areas (subsidies, investments, tax deductions, etc.).

Regional systems (as complex systems) should aim at the increase of resource use. It could be done via minimizing the use of the resources and maximizing the effects of their use. Therefore, regional systems should focus on maximal resource cycling rates within the system. Even though the biotic resources were the key for Region (V), the cycling rates were low and dependency on the external resources was high. It showed a clear disproportion and low efficiency of the resource use. Regional development of such system is fragile as it is dependent on external resources. This situation should be corrected via a regional management system, which could aim at biotic resource diversification and increasing relative importance of other economic sectors, as well as waste flows valorization.

The preliminary results indicated the potential of RSAM as a comprehensive assessment system capable of regional sustainability aspects assessment of a complex. Further application of RSAM was intended for governmental agencies and policy-makers (policy effectiveness analysis, sustainability of a region, and sectoral analysis), producers (position of production from the position of sustainability in regional development), and consumers (lifestyle and consumption impact on sustainability state of a region).

The possibilities of RSAM extension and application required further testing on a few differentiated regions with dynamic time series applications. The specific case study target of this thesis aimed at the provision of the methodology which could be specifically applicable for the analysis of agri-food cluster regions. Today it is not clear how the regions of agri-food clusters can remain the benefits of intensive agriculture for the economy and bear with the increasing problems social and environmental sectors (Tamásy 2013). Using the Oldenburger Münsterland (Vechta and Cloppenburg counties, Lower Saxony, Germany) as an example of agri-food cluster of intensive livestock production, RSAM was tested in terms of application for the regions to identify the hotspots (problematic areas), analyze the relative rates of regional development and estimate the probable paths of regional development. RSAM application for the static and dynamic analyses demonstrated its potential use at the regional level for the identification of inner and outer resources supply and cycling rates, dependency on external resources supplies and rates of self-sufficiency of regions. The application of RSAM to the control region (Hochsauerlandkreis) aimed to provide the relative basis for the sustainability assessment of regional development of the agri-food cluster. It was estimated that the regions of agri-food cluster are in the mature stage of the development, as no progression in terms of economic development was observed for the period of five consecutive years (2008-2012). The overall sustainability state of the compared regions was stable, without significant fluctuations. At the same time agri-food cluster had higher economic resources cycling rates, but had a higher dependency on the external supplies than the control region. Despite a positive overall economic resource state, biotic resources (basis for agri-food production) were used with a lower efficiency and also had higher dependency on external flows (than those in the control region). Such results demonstrated that the regions of the agri-food cluster have a boost of economic activities associated with agri-food production, which strongly rely on external resources.

The analysis estimated two main critical issues for the regional development in the regions of the agri-food cluster. The first one was connected with potential disturbances of external flows of economic resources which might lead to the serious and deep crisis recession (Acemoglu et al. 2013; Delgado et al. 2014; Delgado et al. 2016). In this case the correct strategy of the regional development would be the decrease of dependency on external resources and the diversification of external flows. The second issue was connected with the reliance of the economic activities of the agri-food cluster regions on biotic resources, which had low inner cycling rates and high dependency on external flows. The analysis revealed the dependency of agri-food production on external supplies. Such misbalanced situation posed dangers of rapid shocks connected with the lack of inner resources and disturbances of external flows. In case of shocks of external flows the inner resources would not be able to supply the demand. It would cause the limitations in agri-food production. In order to cope with such a situation the diversification of economic activities of the cluster was needed. The regions should aim in the decrease of development progression on the agri-food production with increase of the value of other activities. Such shift of socioeconomic and environmental development to a more sustainable state is perceived as "sustainability transition" (Truffer and Coenen 2012), which requires a system and holistic vision of a complex regional system.

This thesis introduced a hierarchical integrative framework for the regional sustainability assessment as a set of input-output and cycling models in combination with "direct regionalization" approach. Direct regionalization included the use of regional statistic data from regional sources (not scaled down from national data) and regional real prices for monetary valuation of diverse data. *The assessment through RSAM allowed for the identification of relative regional sustainability state and its dynamics in diverse regional conditions. Moreover, the analysis with RSAM points at critical issues of sustainability transitions and provides a fair comparison basis for the regional development strategies*. Conceptualization, theoretical development and practical applicability of such a framework were the main objectives of the dissertation study.

The development of RSAM was connected with the need to solve specific scientific and practical tasks. One of the biggest challenges was the need to identify the conceptual requirements for the regional sustainability assessment. It led to the determination of regional sustainability as a function of different resources states and interactions. Moreover, the resource approach was adapted accordingly to indicate the social, economic and environmental resources as a reflection of the Triple Bottom Line concept.

From one side, developed RSAM was a modification of traditional methods, based on Life Cycle Assessment, Input-Output Analysis and cycling indices. But from the other side, their association with real statistic regional data on social, economic and environmental aspects of regional development was original. Such a combination of modified traditional methods and original approaches allowed responding to the main requirements of the regional sustainability assessment (combination of TBL approach, estimation of relative position, hotspot identification, results integration and disintegration). The testing of RSAM in this thesis included sub-national, regional case studies (the Oldenburger Münsterland and Hochsauerlandkreis), which were based on the computation of around 150 thousand data points, to show the feasibility of the proposed regional sustainability assessment framework. The case studies also allowed the identification of the developed methodology applicability for the integrated regional sustainability assessment and comparative analysis of separate sustainability issues.

Large amounts of data needed for RSAM application set certain limitations for its application. Following ways of dealing with the limitations were identified: (1) regional authorities (policy-makers, government, planners, etc.) should be involved in data collection (or use available statistical data at regional offices); (2) RSAM would attract regional community network for interactive data submission and collection. Both approaches have their advantages and disadvantages and can be applied depending on the regional requirements or simultaneously.

RSAM also included an original integrative approach to the data combination through a few levels of IOTA. The first lowest level included the analysis of resources interaction within a specific category (for example, economic activities of production companies or biotic resources interchanges). The results of categorical IOTA then were used for the integrative IO matrices construction and analysis (social, economic or environmental assessments). The highest level of results integration was the Integrated Regional Input-Output Table (IRIOT). The analysis of IRIOT allowed estimation of relative sustainability indices as a function of resource use, their cycling in a region and the importance of external resources flows. Such hierarchical assessment system made RSAM adaptable to a wide range of available data, useful for the analysis of separate sustainability categories and applicable for the diverse regional conditions. Application of the same assessment methods to the different levels of RSAM allowed for inter and intra-comparability of results.

6.4. Limitations and outlook

There are quite a few progressive qualities of RSAM. However, it also includes certain limitations. The first one is data dependence. The second is the relative character of RSAM, which requires the comparative analysis with the reference region (or scope of factors). The relative nature of RSAM does not allow for the development of a specific indicator of problematic areas of sustainable development (hotspots), which can be applied separately from overall application of RSAM for the scope of regional aspects. At the same time, once RSAM is applied to a region the estimation of the critical issues is possible.

The biggest challenges of RSAM are connected with the need to have a sufficient amount of data with reliable qualities. The data should cover a representative number of resource types in environmental, social, and economic sectors. The application of RSAM with partial data would result in disproportions and higher weight of some resources in the development of a region. At the same time, RSAM can rely on various data for the analysis, as long as the data are consistent. The dependency on original regional data points to the best application of RSAM as a regional policy and planning tool. Regional authorities have an access to the vast amount of regional data, which are often unavailable to the public. The use of the data for the standardized RSAM will clearly highlight “strong points” and “hotspots” of regional development from the sustainable point of view indicating the areas of urgent actions needed.

Another limitation of RSAM can be connected with the representation of resource flows through their monetization, which might not be a realistic representation of the amount of resources and their weight in a region. In order to eliminate possible mistakes, the prices used for RSAM are specific to each region and time frame. Result representation via physical properties of the resources and their monetized values allow for the comparison and indication of the results and their reliability. Nevertheless, limitation remains for the analysis of integrated input-output regional matrix where all values are presented only in monetized form. Regional monetization, on the other hand, allows avoiding the need for national average data regionalization. There are a few other integrative transformative (unification) units in scientific literature representing relation to energy, emergy, time or weighted points.

The complexity of regional development does not allow for the direct assessment of the activities, effects of investments or policies. For example, direct analysis of investments in regional economy can identify their positive impact on the development of a region. Indirect effects might level down benefits or even indicate negative effect which would have a higher magnitude than initially foreseen benefits. Indirect negative consequences might also have an accumulative prolonged effect (as with the cumulative effects of chemical substances), which is hard to identify. That is why numerous sustainability estimates, based on single value estimation, do not reflect on such indirect consequences.

Direct (single index) sustainability assessment systems also do not reflect on another indirect effect associated with the functioning of a region as a complex system. Improvements in efficiency of activities (economic, resource, temporal) result in a direct decrease of resource consumption for the same function performed. The consideration of such improvements from complex system view (holistic) often reveals that improvement of functional efficiency results in increase of the resource consumption of the overall system. Such “rebound” effect is associated with the social part of a regional system.

Indirect impact and rebound effects can be estimated with a holistic and integrative model, which accounts for interconnections, cycled effects and relative changes. While it cannot be reliably justified that RSAM provides an insight on rebound effects, it is able to reflect on the connections between variable connections in regions. Such overall hierarchical interconnectedness of the RSAM results in relative sensitivity of assessment results. For example, technological changes (increase in efficiency of resource use) are reflected in directly related resource matrices (production, resource use per unit of production). And the analysis of resources amounts involved in the related matrices is changed accordingly. But because of resources integration with other exchange cycles, only minor changes are observable (if any) on integrated levels. Such relative sensitivity to the changes is reflecting the complexity of social interactions. Quite often it is not enough to make the changes in one technology or one production chain in order to improve the sustainability state of a region. Drawing the line between technological or social changes, affecting regional development in a minor degree and major breakthroughs shifting its evolution path is a very complicated task. That is why “sustainable transition” of a region is currently one of the biggest topics of research in regional geography and sustainable science.

“Sustainability transitions” is a complex theoretical issue, which is aimed to provide a scientific basis for the search of more sustainable solutions for the regional development. The complexity and ongoing development of the theoretical basis for “sustainable transitions” do not allow for the estimation of RSAM place in “sustainability transitions” of regional development. However, the conceptual basis of RSAM has similar roots in the approach towards “sustainability” definition. Moreover, similar approaches are used in RSAM for the conceptualization of the adaptive life cycle of regional development, its multi-level interaction and non-linear character. Therefore, it is expected, that set multilevel hierarchical analysis of resources cycling in a region would provide a sophisticated support for the assessment of progression towards a more sustainable state (sustainable transitions) of regional development. This way RSAM is capable to indicate “weak points” of regional development on different levels of socioeconomic organization. At the same time, the thesis was aimed at the development of the regional sustainability assessment methodology for the comparative assessment of regions. The application of RSAM for the assessment of “sustainable transitions” of regions would require further testing with a wide range of regions in numerous geographical and social conditions.

RSAM connection to the “sustainability transition” identifies its further potential development. In the short term, the tools developed in this thesis will be further refined in a number of planned projects. Partially, RSAM might be useful as a part of conceptualization for the project supported by the Ministry for Science and Culture of Lower Saxony (Vorab programme) and Volkswagen foundation titled “Sustainability transitions in food production: alternative protein sources in socio-technical perspective”. The holistic vision of the sustainability and its qualities would be suitable for the identification of the potential paths towards sustainable transition of agri-food clusters. Another potential application is foreseen in projects submitted to Horizon 2020 program. Both projects (“FOODNET – Mapping and Evaluating Food Value Chains and Networks” and EURAS – “European Ranchising Sustainable Solutions for Farming”) include the need of sustainability assessment of agri-food supply chains in regional perspective. RSAM is foreseen as one of the promising methodologies to provide a valuable insight on the results of the projects. It is foreseen, that these projects would allow enriching RSAM with a wider scope of accounted criteria and indicators.

RSAM is a complex methodological framework, although it might be further improved and adapted in order to overcome the limitations and challenges. According to the hurdles identified previously RSAM could be adapted to rely in a less degree on the acquisition of large amounts of data. One of the potential solutions was identified for the substation of absolute data points with correlation indices. Once RSAM is constructed in a region further dynamic application might be performed through correlation indices with partial data acquisition. It might reduce the time of analysis, but might also decrease the quality of results. The potential of correlation indexation inclusion in RSAM should be thoroughly tested.

RSAM can potentially be scientifically improved via combination with risk assessment. The extension of RSAM should improve the specific fields of environmental and social impact assessment. It could, however, be previously concluded that the extension of RSAM would have a probabilistic application, unless the complete spectrum of social, environmental, and economic factors is included. That is why RSAM is foreseen to apply a risk assessment approach to the evaluation of environmental and social impacts with regards to the probability and magnitude in the future.

The long-term perspectives for RSAM are foreseen in the need of multidisciplinary solutions for the establishment of “fair comparison” units for the sustainability assessment. Currently, inappropriate selection of relevant comparison basis causes multiple studies to come to the false conclusions about the sustainability of regions, products or technologies. Despite a long history of searches for the solutions to identify proper comparison units (Dewulf et al. 2008; Guinée et al. 2011), it still remains as one of the core problems for the sustainability assessment. For example, from regional geography perspective, selection of the various approaches for the identification of cluster regions might lead to quite different results (Titze et al. 2011; Hoffmann et al. 2015). Use of the approaches for the comparison unit identification would most probably result in different conclusions. Therefore, a solid framework for the proper selection of relevant comparable units should be developed for the multiple levels and approaches. RSAM could serve as one of the potential systems for the “fair unit selection” of sustainability assessment.

In terms of practical applicability, RSAM requires an optimization and digitalization of data collection from official statistical sources and their automated analysis. There are a few potential possibilities for the automated solutions which may solve the problem of time-consuming data collection and analysis. Current developments in data mining and analysis touching sustainability and supply chains (Song et al. 2016; Perrot et al. 2016; Papadopoulos et al. 2016) would provide a powerful software shell for the optimization and diversification of RSAM.

7 References

7 References

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8 Curriculum Vitae

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Professional Profile

- Professional with 8 years' experience in conducting research, scientific and technical projects management at research institutions.
- Innovative, well trained specialist with experience in successful completion and supervision of national, European and international funded scientific research projects in environment management, lands rehabilitation, natural resources conservation, sustainability and life cycle assessment.
- Author of more than 100 scientific publications of all levels.
- Highly articulate and communicative person with excellent personal and team working abilities, which allow providing volunteer interpreter and lecture services.

Working Experience

Research Associate, Ph.D. Candidate, German Institute of Food Technologies (DIL e.V.), Quakenbrück, Germany, August 2013 – nowadays.

- Life Cycle Assessment of food and related technologies including commercial services for companies
- Management of research proposals (EU Horizon 2020, ERA-NET, CORNET) and research projects implementation
- Students, interns and remote interns supervision in LCA and LCSA
- Research in: Bioeconomy and Sustainability: potential of Life Cycle Assessment for Food Production

Research Associate, Ph.D. Candidate, Institute of Structural Analysis and Planning in Areas of Intensive Agriculture, University of Vechta, Vechta, Germany, August 2013 – August 2015.

- Research in: Bioeconomy and Sustainability: potential of Life Cycle Assessment for Food Production
- Regional System of Sustainability Assessment Development

Visiting Scholar Researcher, Brook Byers Institute of Sustainable Systems, Georgia Institute of Technology, Atlanta, Georgia, USA, August 2012 – June, 2013.

- Participation in research activities of the institute Sustainable Systems Research Group
- Research project implementation according to the terms of Fulbright Scholarship

Academic Council Secretary / Institute Scientific Secretary, Science National Academy of Ukraine: Institute of Nature Management Problems and Ecology, Dnipropetrovsk, Ukraine, May 2012 – August 2012.

- Managed and coordinated research projects of the institute
- Organised planning and reporting activities of research departments

Leading Engineer, Environmental Department, Science National Academy of Ukraine: Institute of Nature Management Problems and Ecology, Dnipropetrovsk, Ukraine, 2007-2012.

- Conducted systematic investigation to establish facts according to the scientific project objectives
- Managed state funded research projects in mining lands rehabilitation
- Organised scientific conferences, their international web pages, communication with international scientists
- Participated in scientific conferences in the field of environmental management
- Participated in completion of scientific project "CLEANSOIL" funded by European Union (6th Framework Programme)
- Received funding for researching mining lands rehabilitation and econetwork construction (45 000 $)
- Participated in research on various subjects/topics of state funded and privately requested scientific projects

Engineer, Environmental Department, Science National Academy of Ukraine: Institute of Nature Management Problems and Ecology, Dnipropetrovsk, Ukraine, 2006-2007.

- Assisted in research projects
- Organised experiments in the field and in the lab
- Collected data and samples (soil, plants, rocks) from research areas

Education

Ph.D. (Doctor), University of Vechta – expected 2017.

- Ph.D. thesis: Bioeconomy and Sustainability: Potential of Life Cycle Assessment for Food Production

Postgraduate Courses in Environmental Safety, Science National Academy of Ukraine: Institute of Nature Management Problems and Ecology, 2006-2010.

- Candidate of Science Degree in Environmental Protection, 2012.

Masters of Science in Ecology and Environmental Protection, Dnipropetrovsk National University, 2006.

- Diploma with honours

Bachelor of Science in Ecology and Environmental Protection, Dnipropetrovsk National University, 2005.

- Diploma with honours

Environmental Studies Credit Certificate, University of Wisconsin – Richland Center, Wisconsin, USA, 2003.

- Dean's List recognition, 2002-2003, GPA 3.52-3.91

Scientific Honours and Awards

- **Falling Walls Lab Finalist & AT Kearney Scholar** at the Falling Walls Conference, 2015
- **Fulbright Faculty Development Grant,** 2012-2013.
- **The Quarry Life Award,** National Competition 1-st place Winner, 2012, 2014.
- **The Best Young Scientist of Dnipropetrovsk Region Award**, 2010.
- **Award of the President of Ukraine for Young Scientists**, 2009.
- **Stipend** of National Academy of Sciences of Ukraine for Young Scientists, 2008-2010.
- **The Best Young Scientist of Dnipropetrovsk Region Award**, 2008.
- **Small Grant** of Bureau of Educational and Cultural Affairs (ECA) of US Department of State, 2008
- **Grant of National Academy of Sciences of Ukraine for Young Scientists**, 2008.
- **Grant of the President of Ukraine** for Gifted Youth, 2006.
- **FSA Undergraduate Exchange Program Grant,** Bureau of Educational and Cultural Affairs (ECA) of US Department of State, 2002-2003.

Professional Societies and Associations

Membership:

Forum for Sustainability through Life Cycle Innovation, since 2015
Institute of Food Technologies, since 2015
American Society of Life Cycle Assessment, since 2015
Italian LCA Network, since 2015
Food Climate Research Network, since 2016

Other Skills and Qualifications

Languages: Ukrainian, Russian (native), English (fluent), German (basic)
Software: Microsoft Office suite (Excel, Word, Power Point), Adobe CS suite (InDesign, Illustrator, Editor), Corel Draw, Sima Pro 7 and 8, LCI Databases
Certificates: Autodesk Building Performance Analysis Certificate, Jan 2014

Most Recent Publications

1. Valsasina, L., Pizzol, M., Smetana, S., Georget, E., Mathys, A., Heinz, V. (2017). Life cycle assessment of emerging technologies: The case of milk ultra-high pressure homogenisation. *Journal of Cleaner Production*, doi: 10.1016/j.jclepro.2016.11.059.
2. Aganovic, K., Smetana, S., Grauwet, T., Toepfl, S., Mathys, A., Van Loey, A., & Heinz, V. (2017). Pilot scale thermal and alternative pasteurization of tomato and watermelon juice: An energy comparison and life cycle assessment. *Journal of Cleaner Production*, 141, 514-525. doi: 10.1016/j.jclepro.2016.09.015.
3. Smetana, S., Tamasy, C., Mathys, A., & Heinz, V. (2017). Regionalized Input-Output Life Cycle Sustainability Assessment: Food Production Case Study. In *Sustainability Through Innovation in Product Life Cycle Design* (pp. 959-968). Springer Singapore. doi: 10.1007/978-981-10-0471-1_65.
4. Raschio, G., Smetana, S., Contreras, C., Mathys, A., & Heinz, V. (2017). Spatiotemporal Tools for Regional Low-Carbon Development: Linking LCA and GIS to Assess Clusters of GHG Emissions from Cocoa Farming in Peru. In *Sustainability Through Innovation in Product Life Cycle Design* (pp. 969-980). Springer Singapore. doi: 10.1007/978-981-10-0471-1_66.
5. Smetana, S., Palanisamy, M., Mathys, A., & Heinz, V. (2016). Sustainability of insect use for feed and food: life cycle assessment perspective. *Journal of Cleaner Production*, 137. doi:10.1016/j.jclepro.2016.07.148.
6. Smetana, S., Tamásy, C., Mathys, A., & Heinz, V. (2016). Sustainability Assessment of Agribusiness Clusters: A Case Study Based on Regional Sustainability Assessment Methodology. *German Journal of Agricultural Economics*. Submitted.
7. Smetana, S., Tamásy, C., Mathys, A., & Heinz, V. (2016). Regionalized Input-Output Life Cycle Sustainability Assessment: Food Production Case Study. *In EcoProduction, Mitsutaka Matsumoto et al. (Eds): Sustainability Through Innovation in Product Life Cycle Design*. Accepted for publication.
8. Smetana, S., Tamásy, C., Mathys, A., & Heinz, V. (2016). Measuring Relative Sustainability of Regions Using Regional Sustainability Assessment Methodology. *Geographical Analysis*. doi: 10.1111/gean.12102. Published online.
9. Smetana, S., Tamásy, C., Mathys, A., & Heinz, V. (2015). Sustainability and Regions: Sustainability Assessment in Regional Perspective. *Regional Science Policy and Practice*, 7(4), 163-186. doi:10.1111/rsp3.12068
10. Smetana, S., Mathys, A., Knoch, A., & Heinz, V. (2015). Meat alternatives: life cycle assessment of most known meat substitutes. *The International Journal of Life Cycle Assessment*, 20(9), 1254–1267. doi:10.1007/s11367-015-0931-6
11. Smetana, S. M., & Crittenden, J. C. Sustainable plants in urban parks: A life cycle analysis of traditional and alternative lawns in Georgia, USA. 2014. *Landscape and Urban Planning*, *122*, 140–151. doi:10.1016/j.landurbplan.2013.11.011
12. Smetana S., Heinz V., Mathys A., Tamasy C. Life Cycle Assessments of regional food production global trends // IFood Conference, Hannover, 8-10 October 2013. Poster presentation.
13. Smetana S.M., Smetana O.M. Environmentally Safe and Economically Friendly Multidisciplinary Industrial Technologies as Innovative Approach towards Sustainable Development // Technologies for Sustainable Development: A Way to Reduce Poverty? 2012. Tech4Dev International Conference 29-31 May, 2012 EPFL, Lausanne, Switzerland. – b_251.