Potential for Sustainable Urban Food Production in a Medium Scale City in Germany

Kay Plat, Andreas Meyer, Petra Schneider and Kai Perret

Abstract In Germany, the percentage of sustainable food production like organic farming increased in the last decades, but is generally still low in comparison to conventional farming. Organic farming provides an approach to increase the sustainability potential of the food supply in the frame of bioeconomy. The assessment of the potential of sustainable urban food supply was in the focus of the present investigation, having as investigation scale the city of Magdeburg in Saxony-Anhalt, Germany. Scope of the investigation was the feasibility assessment of implementation options as well as the perception of the consumers. Following systems were investigated for Magdeburg: urban farming, vertical farming and aquaponics. In terms of the use of urban spaces were considered roof farming, land recycling, as well as the refurbishment of former farms and greenhouses. The feasibility analysis was supported by an option analysis regarding the potential for the use of renewable energies. The results show that even the consumers are willing to pay for organic food, but there are too few sustainable, organic and local urban food products on the market yet. The needed energy for modern urban farming projects is still high in climate areas like the north of Germany. New technologies and the assessment of renewable energy source potential for urban food production is a site specific decision, which might ensure the support of the operational cost of the urban food production systems.

K. Plat · A. Meyer · P. Schneider (✉)
Hochschule Magdeburg-Stendal (FH), University of Applied Sciences
Magdeburg-Stendal, Breitscheidstraße 2, 39114 Magdeburg, Germany
e-mail: petra.schneider@hs-magdeburg.de

K. Plat
e-mail: kay.plat@gmx.de

A. Meyer
e-mail: andreas.meyer@hs-magdeburg.de

K. Perret
Zoologischer Garten Magdeburg gGmbH, Zooallee 1, 39124 Magdeburg, Germany
e-mail: perret.zoomd@icloud.com

W. Leal Filho et al. (eds.), *Towards a Sustainable Bioeconomy: Principles, Challenges and Perspectives*, World Sustainability Series,
https://doi.org/10.1007/978-3-319-73028-8_13

keywords Sustainable urban food production · Urban agriculture
Urban gardening

1 Introduction

Food is a basic necessity of every human being. For this reason, food production and supply is of great importance for the energy supply of every human being. The direct proximity to the consumer and thus direct marketing of the cultivated food within a city has made urban agriculture an integral part of many cities for generations (Gehrke 2012). Urban agriculture has been operating as long as people and cities exist. In the beginnings of urban agriculture food was usually cultivated by the inhabitants of the town in small gardens. Gradually the anchoring methods continued to develop.

There is no clear definition for the current concept of "urban farming". However, some authors have had different understandings to conceptually approach this term. Often, in the literature, there are different approaches for the term "urban farming", it is widely understood to mean any form of agricultural activity within cities and their peripheral areas (Schulz et al. 2013). These include all forms, from food production to animal husbandry to the marketing of non-food products. The size also ranges from shrine gardens to large commercial areas (Schulz et al. 2013). From scientific point of view, Lohrberg (2010) distinguishes between the "actor-oriented approach" and the "space-oriented approach" (Lohrberg 2010). The actor-oriented approach is mainly related to the benefit of the actor (gardener). This approach has mostly personal or non-profit motives and is an important part of many households, especially in developing countries. The actor-oriented approach is referred to as urban gardening and serves above all to improve the quality of life of the individual actor or community (Lohrberg 2010). The space-oriented approach considers the available areas of a city in which commercial agriculture can be operated. These include all economic agricultural uses of urban and peri-urban areas. These uses have both social, economic and ecological motivations (sustainability) and should have a positive impact on the entire urban development (Lohrberg 2010).

In Table 1 according to Lohrberg and Timpe (2011) both forms (urban agriculture and urban gardening) are compared and characteristic properties are presented.

Table 1 Differentiation of urban agriculture and urban gardening according to Lohrberg and Timpe (2011)

Urban agriculture	Urban gardening
• Market-oriented • Professional • Specialized • Adaptable • Land based • Low media effect • Sustainable	• Subsistence-oriented (self-use) • Civically • Quality of life-oriented territoriality • Neighbourhood or neighbourhood reference • Large public awareness (media)

According to the definition of Lohrberg and Timpe (2011), urban farming stands above urban agriculture and urban gardening. It combines all agricultural forms of urban development. To ensure adequate food security in the future, cities with integrated sustainable agriculture could be the solution to ensure the food security of the growing world population (FAO 2009). Germany is currently not affected as much by a food shortage as comparatively developing countries. Nevertheless, sustainable processes and production methods are also indispensable in highly developed countries such as Germany in order to continue to produce food in the future. The cornerstone of sustainability according to the Brundtland Commission (World Commission on Environment and Development 1987) illustrates how the framework conditions for sustainability are and what factors play a role in making a measure sustainable. The Federal Ministry for Economic Cooperation and Development (BMZ) gives information on the definition and sustainability of agricultural production. The criteria for sustainable agriculture are listed below (Ministry for Economic Cooperation and Development 2015):

- Focuses on methods and procedures that improve soil productivity while minimizing the adverse impact on the climate, soil, water, air and biodiversity as well as human health.
- Aims to use as little as possible non-renewable and petroleum-based equipment and replace it with renewable resources.
- Focuses on the local population with its needs, knowledge, skills and socio-cultural values and institutional structures.
- Ensures that the basic needs of food and agricultural raw materials of today and future generations are met in a qualitative and quantitative manner.
- Ensures long-term employment, satisfactory income and dignified and equitable living and working conditions for all people engaged in agricultural value chains.
- Reduces the vulnerability of the agricultural sector to unfavourable natural (e.g. climatic) and socio-economic (e.g. high price fluctuations) conditions and other risks.
- Encourages sustainable institutions in rural areas to promote the participation of all stakeholders and the balance of interests.

Agriculture in the city often differs significantly from conventional agriculture in rural areas. This difference has many origins. The motivation of the individual actors in urban agriculture is different. Today's urban agriculture is mainly due to its social, ecological and economic benefits, which is related to the aforementioned sustainability. A city offers many advantages with its many differences to rural areas. Existing infrastructures, the different climate and short supply chains within a city are just some of the many advantages of urban agriculture (Keuter et al. 2014). The World Meteorological Organization (WMO) defines the city climate as a "local climate changed over the surrounding area." One also speaks of microclimate in a city (Stone 2016). Usually, cities with their climate show a warmer and milder climate than in the surrounding countryside. This is mainly due to the high degree of sealed surfaces and the degree of development (radiant heat and wind reduction) (Stone 2016). In this work, the principles of sustainable agriculture are used as a basis for the further development of sustainable urban agriculture.

2 Overview on Strategies for Sustainable Urban Food Production

2.1 General Overview

The forms and options of urban agriculture are very diverse. In this work, a distinction is made between cultivation strategies and the types of used spaces and/or land. In terms of spaces, respectively lands, the following types are distinguished:

- Use of fallow and brownfield land for food production
- Rooftop farming
- Vertical land use (vertical farming).

The spaces can be used as listed above and managed with the following types of cultivation:

- Organic cultivation of vegetables in soil
- Aquaponics
  - Aquaculture
  - Hydroponics.

2.2 Types of Used Spaces and/or Land

2.2.1 Use of fallow and brownfield land for food production

With increasing building development and sealing of surfaces, there is also a shortage of space in German cities. This consumption is one of the most severe environmental problems of our time (Kaelberer et al. 2005). In the course of the sustainability strategy of the Federal Government of Germany, land consumption in Germany shall be reduced to 30 hectares per day by 2030 (Ministry for Economic Cooperation and Development 2015). Fallow areas might be urban lands which were once used and are no longer in use or which are too small for a building purpose, while brownfields represent former industrial sites, where the industrial use is finished and might have left behind soil contamination but also large spaces eventually with ruins. Inner-urban fallow lands might especially be used for the food cultivation of vegetables and herbs. With the help of the fallow land use for food production, an area can be recycled in principle and new land consumption can

Table 2 Advantages and disadvantages of reuse of brownfield sites according to Kaelberer et al. (2005)

Advantages	Disadvantages
• Sufficient location (centrality, public transport, urban environment, proximity to existing business partners) • Higher value stability or growth, especially in regions with population decline • Saved costs of deployment through the use of existing infrastructure, • Encouraged ecological compensatory measures • Marketing advantage and longer binding time due to building stock with a special flair • Possibility of direct marketing	• Higher costs and delays due to inefficient organization as well as insufficient co-operation between the actors involved • Potential soil risks, e.g. with regard to contaminated sites, munition, etc. in the ground • Costly or restrictive conditions, e.g. preservation of existing buildings • Contour-producing support structures that encourage new greenfield greening • Potential marketing problems due to negative imagery as a “breach area”

be prevented. This land recycling offers many advantages, as well as some disadvantages, which are listed below (Kaelberer et al. 2005) according to the German National Environmental Agency (Table 2).

The greatest challenges for a planned agricultural measure on a fallow land are the legacy of the area. The usage strategy depends on the former use of the fallow land. It might be necessary a waste site investigation and sanitation. The use of land to urban agriculture is of particular interest to planners and cities because of their ecological and aesthetic qualities (Schulz et al. 2013). The larger open space connections resulting from the meadows and fields cultivated in the city ensure unsealed soils and support cold air paths (Lohrberg 2010).

2.2.2 Rooftop farming

There are roofing concepts and agricultural roof surfaces around the world. In Germany, approximately 10 million square meters of roof area are planted every year (Demling and Eppel 2014). In addition to classical roofing, which is generally not used for food production, there are more and more cities in the world that are used primarily for food production. Similar to the use of fallow land, agricultural roofs also offer many advantages for a city such as the improvement of the working and living environment, an improvement of the surrounding climate and noise reduction by good sound absorption (Mann 2013). The increasing use of space can also be countered by the use of roof surfaces.

The commercial cultivation of vegetables on roof surfaces is often done in greenhouses, which can be operated with a variety of cultivation systems (e.g. aquaponics, hydroponics, organic cultivation in soil etc.). As such, the Gotham Greens roof tile in New York is one of the largest commercially used roofing plants worldwide (about 1500 m^2). In principle, every urban agricultural concept depends primarily on the respective location and a detailed site analysis must be carried out in advance. When it comes to the use of the roof for vegetable cultivation, a large number of requirements on the location and the building have to be taken into account in Germany.

The Leibniz Centre for Agricultural Landscape Research (ZALF) provides a recommendation for action and a location analysis in the guide for roof greenhouses “There’s something growing on the roof—rooftop greenhouses”. The ZALF criteria consider the roof structure, the building, the environment and the macro level as an indispensable location criterion for the planning of roof greenhouses (Freisinger et al. 2013).

2.2.3 Vertical farming

The term “vertical farming” comes from English and means “vertical agriculture”. There are different constructions. As a general rule, each type of construction, which is built vertically in height, is designated. In most cases, vertical-farming is building-related and forward-looking, an innovative technology to optimally exploit a space or the surface within a building (Klanten et al. 2011). This can be inside the building as well as at the facade. In buildings there are often shapes that are similar to high-rack bearings. On each level, food is grown with artificial lighting in various systems. The decisive advantage of vertical-farming is, above all, the higher space utilization efficiency of a room. The cultivation area for, for example, vegetables can be expanded a lot.

In case of vertical farming outside of buildings, the façades are more green than farmed. The focus here is less on the production of food, but on the improvement of the city climate (the air purifying effect of the plants) and other advantages for the environment and life quality. The potential for cities is also very large in such a case. Vertical farming buildings might be, for example, unused industrial halls or other unused buildings. Also the vertical construction of shelves in greenhouses is a variant of vertical farming. The shelf load distribution in the building and the statics of the shelves must be taken into account in the case of racking systems. In addition, a modular design of the system should be attempted. With a modular design, one is flexible and the system can be extended or changed as desired (while respecting the room limits).

2.3 Cultivation Strategies

2.3.1 Organic urban vegetable cultivation/Organic cultivation of vegetables in soil

In order to define ecological urban vegetable cultivation, it is necessary to consider in advance what ecological agriculture in general means in Germany and the legal framework conditions. According to the BMZ, the term “organic agriculture” is explained as follows: “Organic farming excludes the use of synthetic plant protection products and mineral fertilizers and tries to work with natural methods and closed plant cycles. There are several different associations and certifications, but it can also be ecologically produced without certification.” (Ministry for Economic Cooperation and Development 2015).

In order to be able to label food in the European Union with an ecolabel (or organic label), the criteria of the EC Eco-Regulation must be complied with. These requirements are very comprehensive and complex. The main criterion of the EC eco-regulation (2007) is the cultivation of plant products in soil: “The supply of plants with nutrients is to be carried out mainly through the ecosystem of the soil” (European Parliament 2007). An objective of the EC Eco-Regulation is to “maintain and promote soil and natural fertility of soil, soil stability and biodiversity of soil to prevent and control soil compaction and erosion and to provide plants Nutrients mainly via the ecosystem of the soil “(European Parliament 2007).

In this investigation organic vegetable cultivation is understood as the cultivation of plants in the soil ecosystem. Here, again, the term soil has to be defined before. The European Commission (2002) defines soil “… as the top layer of the earth’s crust. It consists of mineral particles, organic matter, water, air and living organisms. The soil forms the interface between the Earth (Geosphere), Air (Atmosphere) and Water (Hydrosphere)” (European Commission 2002). Apart from the EC Eco-Regulation and the associated “eco-label”, there are other associations and organizations which provide a “bio-seal” (e.g. Demeter). The requirements for the organic cultivation conditions must always correspond to at least those of the EC Eco-Regulation. Having in view the definition of sustainable urban agriculture, it can be concluded that sustainable agriculture can, but does not have to, comply with the definitions of the legal framework for organic farming. In other respects, ecologically produced products cannot be sustainable in some cases if, for example, the products have long supply and cooling chains in order to reach the customer.

2.3.2 Aquaponics

In 2015, the European Parliament launched a publication entitled “Ten technologies which could change our lives: possible consequences and political effects”. Among these ten technologies, aquaponics is also described as a future-changing and inevitable technology (Woensel and Archer 2015). The term aquaponics is made up of the words aquaculture (fish farming/fattening) and hydroponics (earthless plant breeding on water basis). Aquaponics combines the cultivation of plants and fishes and can be regarded as a closed cycle. The advantages of aquaculture and that of hydroponics can be combined and above all the disadvantages are eliminated to a large extent (Rakocy et al. 2004). The cycle consists of the three main components, fish, bacteria and plants (see Fig. 1).

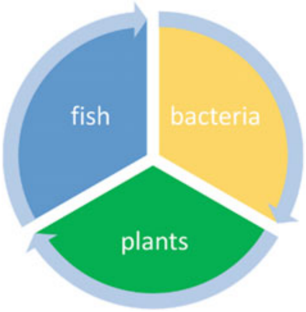

Fig. 1 Cycle of aquaponics

The excrements of the fish are converted by the bacteria into nutrients, which the plants need to grow. The plants clean the water with the absorption of the nutrients (in a high quantity harmful to fish), which then comes clean again to the fish. The circuit closes (Rakocy et al. 2004, 2006; Bernstein, 2013; Wilson 2013). This basic principle of aquaponics is understood in theory worldwide. The application ranges from small home systems to very large commercial installations. Due to the different applications and objectives, the systems differ in their design partly clearly from each other.

2.3.3 Aquaculture

The term “aquaculture” means a controlled breeding of all aquatic organisms, such as fish, molluscs, cretaceous fish and others, in natural and artificial waters and containers. These cultivated organisms are usually owned by the aquaculture operator. In contrast, in the open sea is done fishing Hubold and Klepper (2013). In order to conserve natural fish stocks, it is imperative that the share of fish produced in aquaculture continue to rise and that of the wild catches decrease. The breeding or the fattening of fish (aquaculture) is now spread around the world and is used in various forms. The main strategies are a) aquaculture in buildings, b) in ponds, and c) in the sea. Some of them do not consider a closed cycle, and usually consume enormous fresh water and energy.

Aquaculture in pond farming is practiced almost anywhere in the world (in fresh water). It can be cultivated extensively (e.g. natural ponds with carp) or intensively (e.g. Pangasius fattening with net cages in tropical countries). In the case of intensive aquaculture in pond farms, negative impacts on the environment can usually not be excluded (pollution of soil and water). Aquaculture in the sea is usually realized with the aid of net cages near the coast. Here too, the environmental consequences are usually large. Due to the massive feed rate in e.g. some Salmon farms on the Norwegian coast eutrophicate the coastal sections very much, which has a detrimental effect on the local environment.

2.3.4 Hydroponics

Hydroponics means plant cultivation without soil (or without the soil ecosystem) and with the aid of water. The required nutrients of the crop plants are transported to the roots of the plant by a nutrient solution (nutrients enriched with nutrients) and taken up there. In general, there are many different forms of plants in hydroponics to cultivate. The most important and most frequently used forms are the following according to (LetsGrow 2016; Rokocy et al. 2004).

- NFT (Nutrient-flow-technique)
- Raft-Deep-Water-Culture (DWC)
- Low tide flood systems with substrate beds.

In contrast to conventional plant cultivation in soil, a controlled cultivation in the hydroponics offers some advantages, as there are (LetsGrow 2016; Texier 2013):

- Water savings
- Precise dosage of fertilization
- Reduction of nutrients
- Reduced use of pesticides (preferred use of pest control agents)
- Faster growth of plants
- Monitored and closed environment (e.g., greenhouse).

2.3.5 Further Types of Urban Farming

In addition to the abovementioned land use forms and forms of cultivation for urban farming, further urban forms are described or named briefly. However, these forms are not considered in the variant assessment.

Intercultural and community gardens: are mostly run for social reasons. The main focus is on the community of the individual gardeners, the desire for self-sufficiency and the exchange of information. As a rule, such gardens are not operated with the aim of profitability, but are seen as leisure activities.

Ornamental plants and flowers: refers to the cultivation and marketing of ornamental plants and flowers by nurseries, where the production site often is also a sales location. The cultivation methods are different depending on the nursery. Cultivation is usually carried out in an enclosed site in the open air or in the greenhouse in the city or town. Ornamental plants and flowers generally fulfil aesthetic purposes and are not pre-grown as foodstuffs. For this reason, there is no further elaboration on this topic.

Small animals, bees, algae, mushrooms etc: In today's urban agriculture, small animals, barnacles, algae and mushrooms are increasingly being cultivated and bred. Since these forms are not considered further in the further investigation.

2.4 Scope of the Present Investigation

Scope of the present investigation was the assessment of the potential for sustainable urban food production in Magdeburg, Germany. The investigation approach comprised interviews on the consumer behaviour, material flow analysis of the various forms and options of sustainable urban agriculture, as well as a feasibility and SWOT analysis.

3 Overview on the Situation in Magdeburg

Magdeburg is the capital of Saxony-Anhalt. The city on the Elbe is one of the three upper centres of Saxony-Anhalt and has about 241,000 inhabitants (as of 2016). The city covers approximately 202 km^2 and comprises 129,500 households. Magdeburg is located at the intersection of the river Elbe, Elbe-Havel and Mittelland canal has an important inland port and is an industrial and trading centre. Of economic importance are machine and plant construction, health care, environmental technologies and recycling, logistics as well as the production of chemical products, iron and steel products, paper and textiles.

The Magdeburg area is characterized by intensive agriculture. A total of 7606 hectares of agricultural land are used in the Magdeburg region (Federal Statistical Office Saxony-Anhalt 2017). The Federal Statistical Office (2017) states vegetables were grown in Saxony-Anhalt on an area of 3701 hectares (data as of 2012). The agricultural (vegetables) activities are characterised by the fact that few farms manage large areas (about 29 hectares per operation on average). These are about 124 vegetable farms. Compared to the other federal states, Saxony-Anhalt has the largest vegetable farms (Statistical Office Germany 2013), e.g. approximately 0.5% of agricultural land is used for vegetable production (Ministry of Agriculture and Food Saxony-Anhalt (MULE) 2017). According to Behr and Niehues (2009) the annual lettuce consumption in 2008 amounted to approx. 380 kg per 100 households in Germany. Applied to Magdeburg, this would compare to an approximate consumption of 492,100 kg of lettuce per year. If it is assumed that approximately 10% of the lettuce demand are covered by organic lettuce, an annual consumption of 49,210 kg of organic lettuce can be concluded for Magdeburg. With an average fish consumption in Saxony-Anhalt of 5.6 kg fish per year, the market demand for fish can be concluded with 1350 tonnes per year in Magdeburg.

In Magdeburg are 13 locations with activities on urban organic gardening (as of 2017). One example is the communal garden “Jardin de Rayon” (see Fig. 2). The garden was established on a former fallow land in the middle of the city.

Fig. 2 Development of inner-urban fallow land in Magdeburg: the intercultural and community garden “Jardin de Rayon” (Leipziger Str.)

4 Investigation Strategy

The methodology used for the assessment of the potential for sustainable urban food production in Magdeburg consisted of a background analysis (with a literature review), complemented with the collection of empirical data from interviews of the public. Further, the background analysis was supported with a SWOT analysis. Further was prepared a material flow analysis with the scope of the comparison of the options of sustainable urban food production methodologies in Magdeburg. Within the scope of this investigation, a survey was conducted to derive a tendency for the potential sales of urban food products in Magdeburg. The title of the survey was: “Urban Farming Potential in Magdeburg”. The survey was created and implemented online with the help of www.umfrageonline.com. The survey was active from 15.02.2017 to 31.03.2017 (six weeks). A total of 347 people participated.

In the first part of the survey, general demographic background to respondents were determined, like place of residence, the age, the sex and the current professional status. The statement about the place of residence is decisive, since only answers from people who live within 100 km Magdeburg are taken into account. This serves to determine the most exact purchasing and consumption behaviour of Magdeburg citizens. In the second part of the survey, the consumer behaviour of Magdeburg citizens was questioned with regard to fresh vegetables, fresh herbs and fish products. It was asked where the products are purchased/purchased, how often they are purchased/purchased, how much customers are satisfied with the range of products in Magdeburg. The final part of the survey was devoted to the potential implementation of urban agriculture in Magdeburg and the willingness to buy and accept urban food products.

From the potential forms of sustainable urban agriculture described in Chap. “Service-Based Bioeconomy—Multilevel Perspective to Assess the Evolving Bioeconomy with a Service Lens”, there are a total of six possible variants which are considered in the investigation, as shown in Fig. 3. The varieties

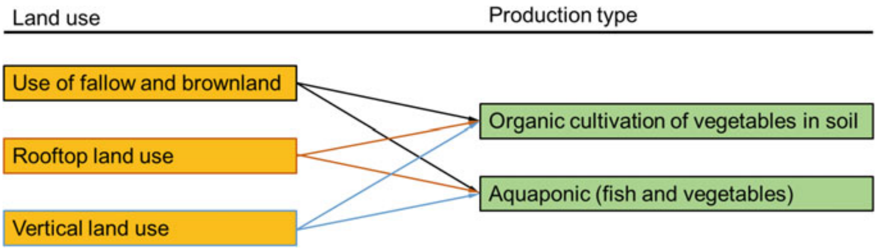

Fig. 3 considered variants for the sustainable urban farming option analysis in Magdeburg

of fallow land use in combination with aquaponics, fallow land use in combination with organic cultivation of the soil, use of the roof in combination with aquaponics, use of the roof in combination with organic cultivation of vegetables in soil, vertical farming use in combination with aquaponics and vertical farming use in combination with organic vegetable cultivation in soil. Beside the technical evaluation of the variants, was prepared a SWOT (Strength, Weakness, Opportunities, Threats) analysis, which is an instrument for positioning and strategy development (David 1993; Helms and Nixon 2010). The existing strengths, weaknesses, opportunities and risks are compared. The goal is a view of the situation on the basis of strategic decisions that are taken by Strengths—*obtained or expanded*, Weaknesses—*to be reduced*, Opportunities, and Threats—*to be eliminated*. SWOT is an abbreviation for Strengths, Weaknesses, Opportunities and Threats.

The resulting variants are summarised as follows and are illustrated in Fig. 4:

- Variant I—Use of fallow land and brownfields with aquaponics
- Variant II—Use of fallow land and brownfields with organic farming
- Variant III—Rooftop with aquaponics
- Variant IV—Rooftop with organic farming
- Variant V—Vertical farming with aquaponics
- Variant VI—Vertical organic farming.

The general scope of investigation is defined by the claimed area of 2400 m^2. The resulting considered six variants (in the following numbered I to VI) require an area of 2400 m^2. In addition, an optimal location for the variant consideration is assumed. Factors that ensure a fundamental decision for the location for the variants are:

- Low shading through adjacent buildings
- No pollution of the land and the floor
- Good infrastructure
- Location: Magdeburg (climatic conditions).

For the aquaponics variants (I, III and V), was considered the fish tilapias (*Oreochromis Niloticus*) and for the hydroculture lettuces *(Lactuca sativa var. Capitata).* The fish are kept at a stocking density of 40 kg/m^3. The stocking density indicates how many kilograms of fish that are grown in one cubic meter of water.

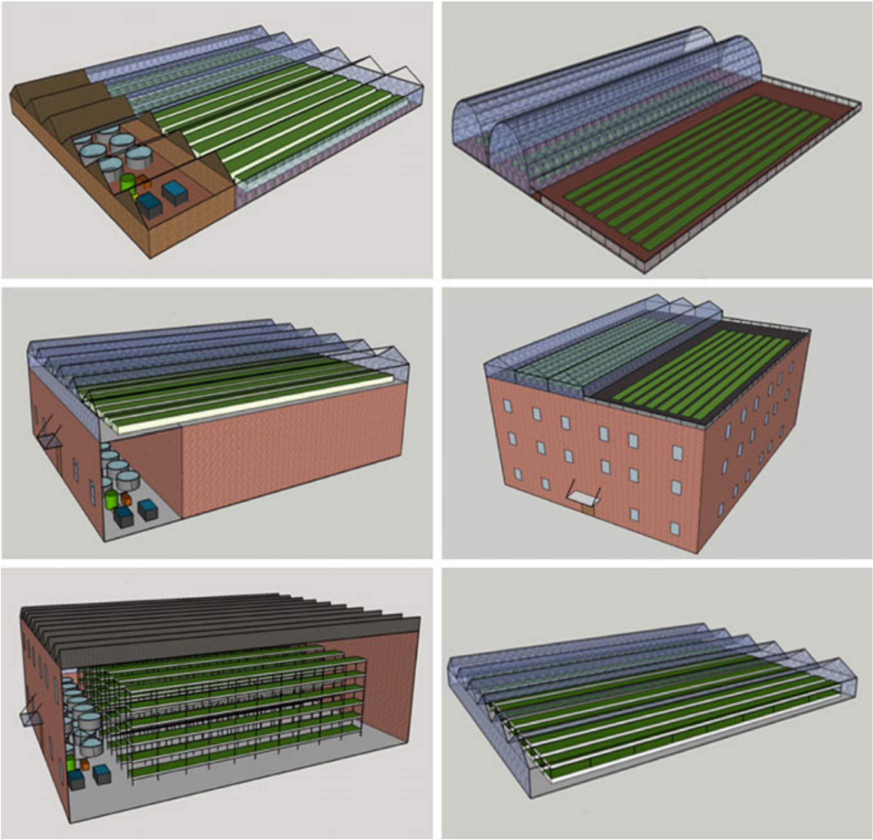

Fig. 4 Illustration of the considered variants for the sustainable urban farming option analysis in Magdeburg

The feed rate is 1–5% of the total fish mass per day. This ensures a continuous growth of fish until slaughter, which is carried out after approximately six months. A fish weighs between 400 and 600 g of total weight during slaughter. In the illustrated aquaponics systems, a ratio of 1: 1.5 (1 m^3 of water volume fish tank to 1.5 m^3 nutrient solution for plants) is striven for. The fish grow in fish tanks with different capacities (depending on the variant). In addition, a drum filter for the separation of the solid particles (sewage sludge) and a biofilter (nitrification and denitrification) are connected to the aquaponic system.

The water cycles for aquaculture and those of the hydroculture are decoupled systems. The process water, which is in the water cycle for the plants, does not return to the fish, but circulates continuously in the hydroculture system. The sewage of the fish reaches the water cycle for the plants after filtering and denitrification. It is treated in a separate basin and the water parameters adjusted to the needs of the plants (pH value, additional trace elements, etc.). An UV filter also

Table 3 Technical planning data

Variant criteria	Variant I, use of fallow and brownland with aquaponic	Variant II, use of fallow and brownland with organic farming	Variant III, rooftop using with aquaponic	Variant IV, rooftop using with organic farming	Variant V, vertical farming with aquaponic	Variant VI, vertical farming with organic farming
Area [m^2]	2400	2400	2400	2400	2400	2400
Greenhouse	VENLO	Foil greenhouse	VENLO	VENLO	No greenhouse	VENLO
Greenhouse used area [m^2]	1520	1200	2400	1200	2400 indoor area	2400
Outdoor area [m^2]	0	1200	0	1200	0	0
Building use (indoor)	Yes for aquaponics system	No	Yes for aquaponics system	No	Yes for aquaponics system	No
Temperature minimum [°C]	20	5	20	10	20	10
Plant cultivation area [m^2]	1064	1680	1540	1800	5760	3520
Fish tank size (total) [m^3]	320	0	504	0	625	0

disinfects the water. The amount of water added to the cycle of hydroculture is about 5–10% of the total water volume of aquaculture per day. Since the water does not return into the fish water cycle, the water loss must be compensated by fresh water (e.g. from rainwater).

Hydroculture is planted in Deep-Water-Culture (DWC). The height of the bees is 0.3 m, which also corresponds to the water level in the planting basin. The beds have a width of 2 m and vary depending on the variant in your length. The lettuce plants are pre-grown prior to hydroculture, for example, in coconut substrate before they can be used in the hydroculture. The lettuce cuttings are then inserted into openings of a styrodur plate after pre-breeding. The plant roots are then directly in the water and the lettuce heads are held by the styrodur plates on the surface. A plant density of 20 lettuce heads per square meter is considered. The lettuce heads in hydroculture have a harvest weight of approximately 300 grams and can be harvested in a harvest interval of 4 weeks.

For the organic farming variants (II, IV and VI), lettuce (*Lactuca sativa var. Capitata*) is used as planting culture. The plant density is between 8-11 plants per square meter. The ecosystem soil is used as a plant substrate. The composition varies depending on location. A compost allowance of 2 kg/m^2 is calculated per harvest interval. The harvest interval differs depending on the variant and lies between 6-12 weeks for organic lettuce cultivation. The water requirement is assumed to be about 640 L/m^2 and harvest interval. Depending on the variant, this results in an additional water requirement (apart from rainfall) of approx. 140–640 L per crop interval and square meter. Table 3 shows the planning details of each variant.

5 Results

5.1 Consumer Behaviour

Because of the criterion that only respondents within a radius of 100 km of Magdeburg can be taken into account, the number of participants was 322 (n = 322). 81.7% of the respondents live directly in Magdeburg, 10.7% within a radius of 50 km and 7.7% within a maximum of 100 km. Gender distribution is relatively balanced (52% male, 47% female, 1% no response). The largest share of respondents (43.3%) was in the age between 26 and 35 years. The majority of respondents to the survey were employees with a percentage of almost 50%. 35% of respondents were students.

The reported frequency of purchase of fresh lettuce and herbs was 70% of respondents at least 0–1 kg per week. 18% of them informed to buy more than 1 kg per week. Approximately 18% of the respondents consume at least 1 kg fresh leaf vegetables and herbs monthly. The main sources of supply are supermarkets and discounter with approximately 83%. Nearly 96% of the interviewees said they buy up to 1 kg of fresh vegetables every week. Approximately 8% of the respondents consume at least 1 kg of vegetables per day and 46% of them per week. The main portion of fresh vegetables is purchased from supermarkets. Approximately 1% of the respondents stated that they cultivate the majority of the vegetables themselves, and about 3% obtain their vegetables from a weekly market and organic food store. Generally, the majority of respondents is satisfied with the supply of fresh vegetables in Magdeburg. It is, however, to be stated that the criteria of the regionality of the products was answered as unsatisfactory by 33.5% of the participants. The supply of climate-friendly vegetables in Magdeburg was also stated to not be satisfactory for approximately 27% of the respondents. 87% of the interviewees pay attention to freshness and quality when purchasing fresh vegetables. In the third place (74%), the respondents are buying vegetables that are of regional origin. For 68% of the respondents is important the price and for 67% climate friendly production.

In addition to the consumption behaviour of vegetables, the survey also examined the consumption behaviour of fish in Magdeburg. To the question about the frequency of purchasing fresh fish 41% of the interviewees responded “never or less than monthly”. Only about 7% of the interviewees buy fresh fish every week. Nearly 24% buy their fish in frozen form and 6% only as a processed product (e.g. smoked salmon). 16% buy up to 1 kg of fish per month. Due to the small consumption level of fish, only 185 interviewees responded to the question “Where do you buy/buy the bulk of your fish”, informing that almost 80% buy in the supermarket and discounter. The percentage of fish bought in the market is 1.6%, 2.7% directly at the producer, 5.4% are fishing themselves, and 5% refer to their fish without mentioning other sources. Many participants did not give any information about their satisfaction on the fish availability. In addition, those interviewees who responded are not very satisfied with the supply of fresh fish in Magdeburg. The interviewees, who are not satisfied with the supply of locally produced fish in Magdeburg, sum up to 25%. According to the responses, 17% of the respondents would like more fish from climate friendly breeding. 84% regard freshness and quality as the main criterion when buying fish. 75% of the respondents appreciate a seal of sustainability, 67% consider most important the price, 63% the climate-friendly breed, 62% the fish’s regionality, and for 53% of the respondents it is important that the fish comes from aquaculture.

67.5% of the interviewees would buy more vegetables grown on roof surfaces, 63.4% of the participants prefer a fallow land use for vegetable cultivation, and 42.3% vertical farming. 35.5% prefer rural food products. 30.9% consider aquaponics products to be attractive. The results of the survey indicate a potential for urban fish and lettuce. Consumers want more regionality and a large proportion of respondents would support urban agriculture with the purchase of products. In addition, there is no commercially operated urban farming company in Magdeburg at this time (2017).

5.2 Results of the Option Analysis

In order to achieve comparable results, the functional unit of the material flow analysis (MFA) was set to 1 kg of lettuce. In the case of a material flow analysis, a determination of the examination framework (system limits) is mandatory. Furthermore, the system limits are defined and listed, which is considered within the substance flow analysis and what is not. In the MFA was looked at:

- Feed requirements of the fish or according to the variant the fertilizer application [Kg]
- Energy supplies (thermal and electrical energy in [kWh])
- Water requirements [m^3], waste production [Kg], and land consumption [m^2].

It was not considered:

- Pre-value-chains of energy generation, water supply, and fodder production
- Individual biochemical intermediates within the system
- Nutrient composition of the waste
- Manufacture of plant seeds, breeding of fish
- Cost
- Processing, sale and consumption
- Production of the system components: greenhouse, building, substrate and medium (e.g. stone wool), fertilizer, fish tanks, plant beds, pots, beneficiaries, etc.

The individual biochemical intermediates within the sub-processes of the systems (nitrogen, phosphates, etc.) were not considered because of the system delineation. The general material flows for lettuce and fish production are summarised in the Figs. 5 and 6. All calculations are based on the functional unit 1 kg of lettuce, and

The specific consumption of the urban organic agriculture variants to produce 1 kg of lettuce differ, in some cases considerably. It becomes clear that the size of the cultivation area also reduces the specific substances consumption for the production. In addition, it must be noted that the required thermal energy depends considerably on the installed premises (e.g. greenhouse or greenhouse and isolated building). Variant V (vertical aquaponics in a building) has the best heat balance, but requires an artificial lighting due to the lack of solar radiation in the building.

Variant V has the lowest specific consumption for the other parameters. It has also to be stated that the specific water consumption of the ecological variants (II, IV and VI) is very high. This is due in particular to the high degree of evaporation and infiltration of the water. Also in terms of the land consumption, the organic farming options have significantly worse results than the aquaponics variants. The input and the output material flows of the production process of 1 kg lettuce are shown in Figs. 7 and 8.

As can be seen in Fig. 9, the specific outputs of the individual variants do not differ significantly. The smallest specific waste is produced by variant VI.

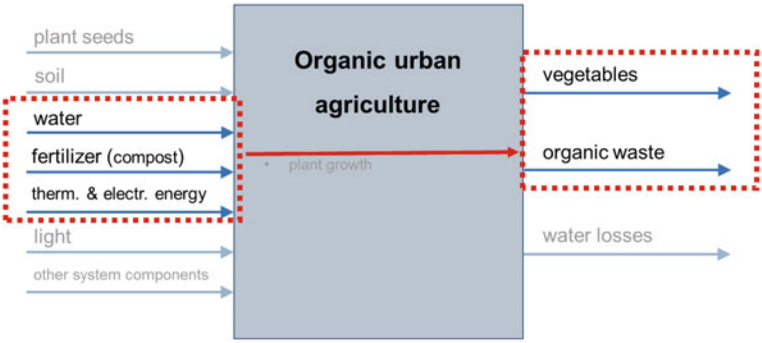

Fig. 5 Qualitative material flow of the urban organic agriculture system

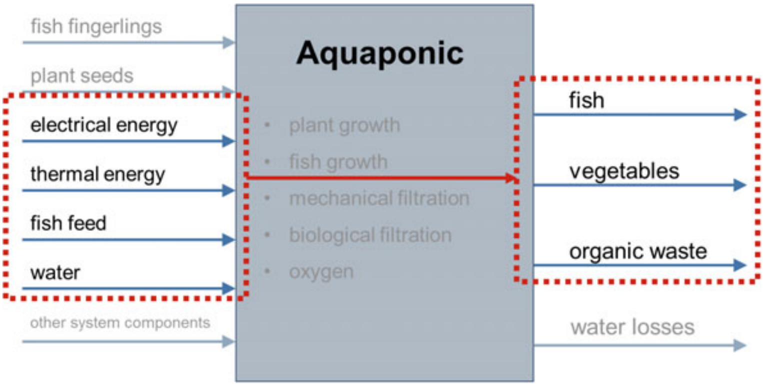

Fig. 6 Qualitative material flow of the aquaponic system

This is mainly due to the vertically used area. Variant V also has a relatively low specific waste output. The organic farming options do not have fish products as output. For the aquaponic options, the unutilized feed and the mortality of the fish are included in the balance of the resulting waste (Tables 4 and 5). This is the reason why the specific wastes are slightly higher in variants I, III and V than in variants II, IV and VI. Both options, urban organic farming and aquaponics, are assessed through a SWOT analysis. A final evaluation of the results is made in Table 6.

On the basis of the market analysis, the assessment according to sustainability criteria, the material flow analyses, the carbon footprint and the SWOT analysis, a rating matrix was developed (see Table 6). This evaluation matrix with the defined evaluation criteria is used to determine the variant with the highest potential for implementation in Magdeburg. The following criteria have been taken into account in the assessment: negative effects on the soil ecosystem, water use, nutrient requirements (compost or feed), fertilizer use, pesticide, herbicide and fungicide

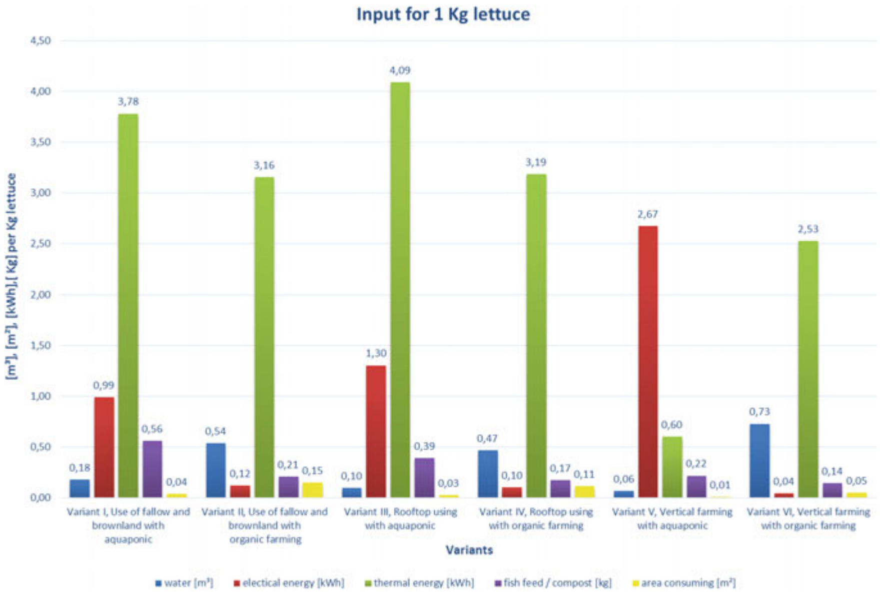

Fig. 7 Input comparison of the variants

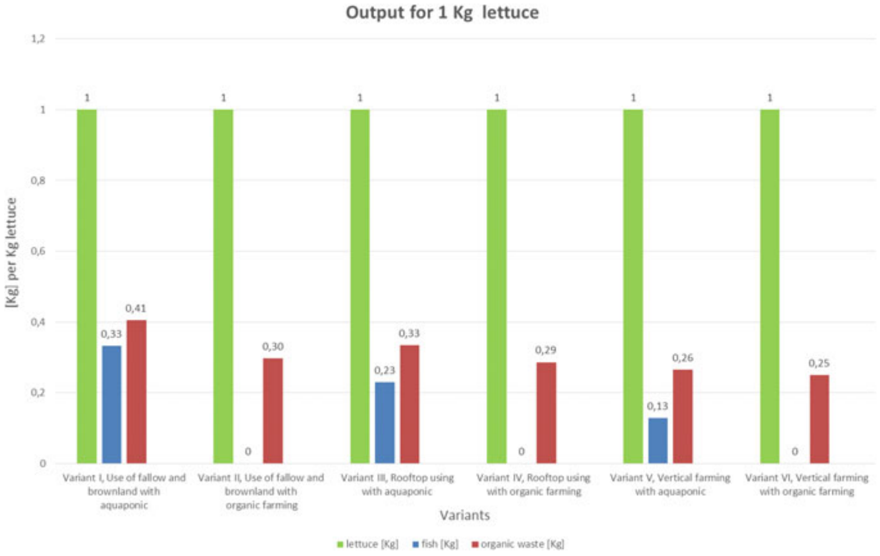

Fig. 8 Output comparison of the variants

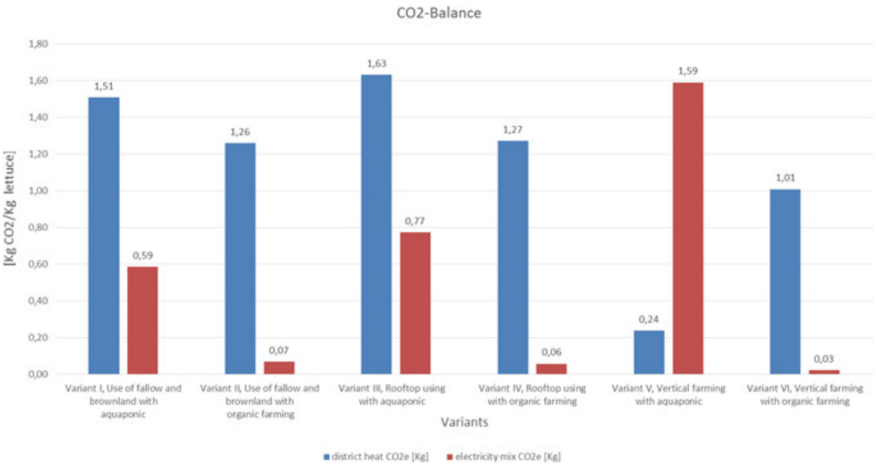

Fig. 9 CO_2-balance of the variants

Table 4 SWOT analysis of organic vegetable cultivation in soil

Strengths	Weaknesses
• Creation of green spaces in the city promotion and conservation of the soil ecosystem • Improving the quality of life in the city (air purification, etc.) • Low investment costs • No use of pesticides • Abandonment of chemical fertilizers • Partially healthier due to lack of treatment of the plants • Mostly low imissions (climate friendly) • Small transport routes of the products (urban environment) • Regional and decentralized food supplies in the city • Waste materials can usually be composted and used as fertilizer • Low to no energy requirement (artificially generated)	• Exposed to weather conditions in the open air • High water consumption (evaporation and seepage) • High area consumption per kg of food produced • In some cases lower yields compared to aquaponics
Opportunities	Threads
• Recycling of biomass (plant waste is composted) • More important in the future as higher food demand (creation of food security) • Easy implementation by private individuals possible for the production of vegetables for their own needs • Use of land under cover (Urban Upcycling) • Possibility of promoting environmental education in the city	• Environmental impacts (loads of the soil and air can accumulate in food) • Pests or diseases can lead to crop failure • Large area utilization

Table 5 SWOT analysis for the aquaponics system

Strengths	Weaknesses
• Closed material flow • Reduced consumption of materials (water, energy, etc.) • High yields • No use of pesticides through abandonment of chemical fertilizers • Space saving • Low emissions (climate friendly) • Low impact on air, water and soil because closed system (delimitation through, for example, greenhouse) • Small transport routes of the products (urban environment) • Fresh fish and fresh vegetables (regional and decentralized food supply in the city) • Time-efficient (plants grow faster in hydroculture) • very sustainable (through energy supply with renewable energies)	• Mostly high investment costs • In case of non-self-sufficient energy supply, high energy costs • In the case of incorrect implementation, a form of mass factory farming • No organic certificate for vegetables and fish according to European Union law • Fish feed mostly still consists to a large extent of fish meal or - oils from fish from wild • In large scale high labour costs
Opportunities	Threads
• In the future even more important, since higher food demand (creation of food security) • Possibility of automation • Decentralized energy supply through renewable energies possible • Utilization of biomass (plant waste, sewage sludge, fish excrements, fish residues after, for example, filleting) • Development of a label or certificate for organic production in aquaponics • Use of buildings (Urban Upcycling) • Use of waste heat from large heat producers (such as power plants, waste incineration plants, etc.) • Possibility of promoting environmental education in the city • Alternative feed for the fish (e.g. insects, water lenses, etc.)	• By cultivating non-urban areas, loss of habitat for native flora and fauna. • The cultivation of carnivorous fish usually encourages the overfishing of wild catches (often 60% of captive fish) • Excessive stress levels and associated disease susceptibility (medication use) • Close to nature fish breeding difficult and challenging

use, waste generated, negative effects on water, the nutritional value of the products, the market potential for Magdeburg and the land consumption. A value was determined for each criterion. These range from 1 (very low) to 3 (medium) to 5 (very high). The evaluation is based on the previous analyses and evaluations of the individual variants.

Table 6 Evaluation matrix of variants

Evaluation criterion	Variant					
	Variant I, use of fallow and brownland with aquaponic	Variant II, use of fallow and brownland with organic farming	Variant lll, rooftop using with aquaponic	Variant IV, rooftop using with organic farming	Variant V, vertical farming with aquaponic	Variant VI, vertical farming with organic farming
Negative impact on the soil ecosystem	2	1	2	1	2	2
Water consumption	2	4	1	4	1	5
Nutrient requirements (fish feed/ compost)	4	3	4	3	3	2
Fertilizer use	1	1	1	1	1	1
Pesticide, herbicide and fungicide use	1	1	1	1	1	1
Electrical energy consumption	3	1	3	1	4	1
Thermal energy consumption	4	2	4	2	1	3
CO_2 emissions (greenhouse effect)	4	1	5	1	3	1
Emerging waste	2	3	2	3	2	2
Negative impact on water bodies	1	2	1	2	1	2
Nutritional value of products 1 very high and 5 very low)	1	4	1	4	1	4

(continued)

Table 6 (continued)

Evaluation criterion	Variant					
	Variant I, use of fallow and brownland with aquaponic	Variant II, use of fallow and brownland with organic farming	Variant lll, rooftop using with aquaponic	Variant IV, rooftop using with organic farming	Variant V, vertical farming with aquaponic	Variant VI, vertical farming with organic farming
Market potential Magdeburg (1 very hiqh and 5 very low)	2	1	2	1	2	1
Land use	2	5	2	4	1	2
Total	29	29	28	28	23	27

1 very low; *2* rather low; *3* medium; *4* rather high; *5* very high

For each variant a total sum was determined. In analogy to the ecological footprint a small total sum is the optimum. The smallest total of the evaluation was determined for variant V: vertical area use in combination with aquaponics.

5.3 Design Sample for Sustainable Urban Food Supply

A pilot application is foreseen at the Zoo in Magdeburg, to be used as “Farm in the Zoo”. In the project is planned to expand the existing site with an aquarium and a river landscape. Beside this investment there will be still enough space of of 3000–6000 m^2, depending on the detailed design, to host the urban farming space, which considers a rooftop farming with an aquaponics system. For the new construction of an aquaponics system, two planning variants were developed, each depending on the available space. The first variant is to build the facility evenly, the other option is to build the hydroculture on the roof of the new building. In both cases, aquaculture is to be integrated into the future building. The process engineering operation is the same in both possibilities, but not the heat demand. An aquaponic system with a total area of 2556 m^2 is planned for both cases, out of which 2256 m^2 are foreseen for the hydroponics system containing 1430 m^2 for plant cultivation. The remaining 300 m^2 of space are allocated to the aquaponics system. Depending on the season, the hydroponic part of the plant is operated as a warm greenhouse (April–September, 20 °C) or cold greenhouse (October–March, 15 °C). In addition to the 1440 m^2 of the plant area, the system includes 12 fish tanks each with 18.5 m^3 water volume and a stocking density of 50 kg fish per basin (Fig. 10).

The pre-designed option was assessed through a CO_2-balance, taking into account several options for the energy supply of the system with renewable energies. When looking at CO_2 emissions, it becomes obvious that the emission of the

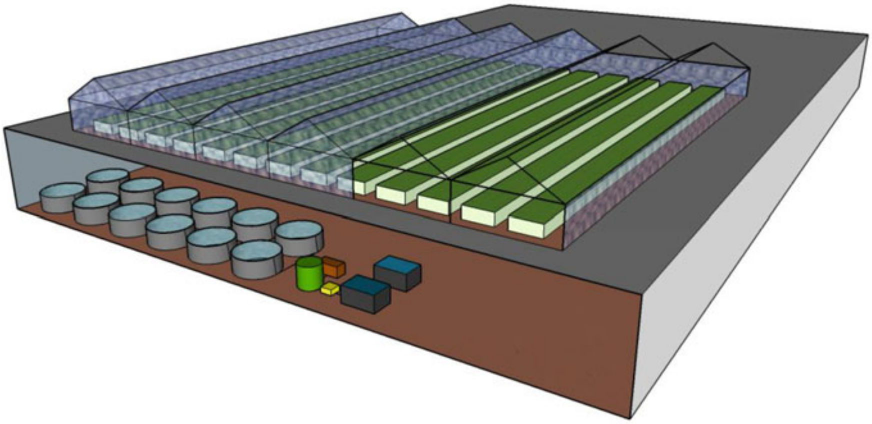

Fig. 10 design sample for sustainable urban food supply at Zoo Magdeburg

power supply is determined by the operation of the process technology, since it has the highest energy requirement. In relation to the process technology, solar thermal energy or geothermal energy needs about 1.7–3.3% of its demand. CO_2 emissions are correspondingly the same. When natural gas is used for the supply of electricity, the CO_2 release is 32,667 kg for process technology (33,790 kg for a process with geothermal energy). As comparison, 80,239 kg are released for the process technology with energy supply through brown coal (82,999 kg for a process with geothermal energy), resulting in the case of brown coal in 145.6% more CO_2 than with natural gas.

In the case of heat supply, the differences are caused by the design of the planning variants, since the hot water requirement is the same in both cases. For example, when installing rooftop cultivation 7 m above ground, 14.5% less heat is required in comparison to an installation on ground level resulting from more intensive global radiation which reaches the building. In the case of ground level installation, the shadow volume caused from adjacent buildings is significant larger. With heating through household waste, 21,743 kg of CO_2 are generated in the design variant with ground level planning in comparison to 18,585 kg CO_2 at 7 m level. In contrast to this, a heating with brown coal releases 54,089 kg CO_2 in the case of ground planning (46,233 kg in the design option at 7 m above ground). This results in 149% more CO_2 released with brown coal as energy source in comparison to household waste incineration. This means, the consumption of primary energy sources for the power generation reaches its maximum value for brown coal utilization. The operation power for the process technology needs 41,583 kg brown coal (43,013 kg for geothermal engineering). By comparison, for natural gas use, 7,321.01 kg (7,572.81 kg for geothermal engineering) must be provided. Thus the mass consumption of brown coal is 468% above that of natural gas.

In terms of renewable energy supply for sustainable urban farming systems, it is to be summarised that not all forms energy supply and storage are realizable for any plant planning size and system. The significant factors for an autonomous energy supply are the following four important characteristics which must be taken into account during planning: the meteorological conditions at the site, the energy requirements especially of the aquaponics system, the urban conditions, and the potentially applicable renewable energy systems. The determining condition for the sustainable urban farming systems is the fact, if a fish production through aquaponics is included as this needs significantly more energy. Further, the urban conditions play a significant role, especially for the performance of the solar and photovoltaic collectors. Due to this fact, the design indicates an advantage for a separation of hydroponics for a roof surface and aquaculture on a level ground.

6 Conclusions

The scope of this work was to conduct a variant assessment for urban agriculture in order to evaluate the option with the highest implementation potential in Magdeburg. The study of the variants has shown that urban agriculture has a high potential in Magdeburg, based on the results of the survey and the option analysis. The consumers in Magdeburg are willing to buy urban agriculture products.

If all variants are considered, variant V (vertical farming with aquaponics) has the highest implementation potential for Magdeburg. A cost estimate has shown that the costs of the labour for a non-automated system are very high compared to other costs. If the Vertical Farm would be automated, the labor costs would decrease. It has been shown that the valuation of the variables is mainly based on the planned planning variables of the system. If individual parameters such as, the location or the types of greenhouses, etc. are modified, the entire result of the specific consumption of a variant modifies accordingly. The main planning parameters are the location, the size and the type of the system which is used (e.g. aquaponics or organic culture in soil). These criteria have an enormous impact on the required electrical and thermal energy, water demand and other input and output variables.

The location has been the same in the considered variants and has been prioritized from an optimal location (little shading and good infrastructure). The analysis of the energy requirement showed that a selection of the materials used (greenhouse glazing and building insulation) had a significant impact on the energy requirement. Good and modern insulation materials with a low heat transfer coefficient have the properties to reduce the heat energy requirement by 70%. The electrical energy supply depends on the system used and the process technology involved. With the help of the study on self-sufficient energy supply from renewable energies, it has been shown that large urban farming projects such as “Farm in the Zoo” can be supplied only partly through renewable energies. The energy demand for the analyzed variant is too big in a climate like Magdeburg.

Due to the multiple influences, the preferred variant for urban agriculture is always to be derived from the location and the project size. Each project must be considered and analyzed. The success of each urban agriculture project also depends on the respective demand of the consumers. This work can be used as a basis for further planning in urban agriculture.

References

Behr H-C, Niehues R (2009) Market and sales. Land Building Research—Special Issue 330 (2009) 69 (in German)

Bernstein S (2013) Aquaponic gardening: a step-by-step guide to raising vegetables and fish together

David F (1993) Strategic management, 4th edn. Macmillan Publishing Company, New York, NY

Demling F, Eppel J (2014) *Vegetables on the roof*. Gemüse auf dem Dach, Bayerische Landesanstalt für Weinbau und Gartenbau, Bavarian Wine And Gardening Agency, In German

European Commission (2002) Towards a strategy for soil protection—COM 179

European Parliament (2007) Organic production and labelling of organic products. Council Regulation (EC) No 834/2007 of 28 June 2007 and repealing Regulation (EEC) No 2092/91

Federal Statistical Office Saxony-Anhalt (2017) Land survey and actual use of agricultural land in hectares Magdeburg, interactive database. www.statistik.sachsen-anhalt.de, 18 Apr 2017

Food and Agriculture Organization of the United Nations (FAO) (2009) Food for the cities

Freisinger UB, Specht K, Sawicka M, Busse M, Siebert R, Werner A, Thomaier S, Henckel D, Galda A, Dierich A, Wurbs S, Grosse-Heitmeyer J, Schön S, Walk H (2013) There's something growing on the roof—Rooftop greenhouses—Idea planning implementation. Leibniz Centre for Agricultural Landscape Research (ZALF), Muncheberg

Gehrke J (2012) Urban gardening—How the gardens return to the city, NABU Federal Association. In German: *Urban Gardening – Wie die Gärten in die Stadt zurückkehren,* NABU-Bundesverband

Helms MM, Nixon J (2010) Exploring SWOT analysis—Where are we now? A review of academic research from the last decade. Journal of Strategy and Management 3(3):215–251

Hubold G., Klepper R. (2013). The importance of fishing and aquaculture for the global food security. Thuenen Institute for market analysis (in German)

Kaelberer A, Klever, S, Lepke, T (2005) The future lies on brownfield sites—reactivation of urban land reserves, ICSS of the Umweltbundesamt (ed.), In German: *Die Zukunft liegt auf Brachflächen – Reaktivierung urbaner Flächenreserven*, ICSS des Umweltbundesamt (Hrsg.)

Keuter V et al (2014) Building-Based Food Production—Where we stand today and what will be possible in the future. In Farming and Fraunhofer Institute for Environmental Safety and Energy Technology UMSICHT, Symposium: "Urban Horticulture—Production returns to the city"(in German)

Klanten R, Ehmann S, Bolhöfer K (2011) My Green City – Back to nature with attitude and style. Gestalten Verlag GmbH & Co, KG

Letsgrow (2016). Workshop on aquaponics and its components, 05 Nov 2016

Lohrberg F, Timpe A (2011) *Urban agriculture—new forms of primary production in the city*. Specialist magazine "Planerin" 5/2 (in German)

Lohrberg F (2010) Urban agricultural landscapes. In: Published in Valentin (ed) The return of the landscape (in German)

Mann G (2013) Gründach – Urban Farming. Optigrün international AG, Journal Dachbaumagazin 1–2

Ministry of Agriculture and Food Saxony-Anhalt (MULE) (2017) Plant production and economic importance (in German). Online available: https://mule.sachsen-anhalt.de/stichworte-a-z/landwirtschaft/pflanzenproduktion/gemueseanbau/gemueseanbauvolkswirtschaftlichebedeutung/?q=schule, 18 May 2017

Ministry for Economic Cooperation and Development (BMZ) (2015). What is sustainable agriculture? German Association for International Cooperation (GIZ) GmbH (in German)

Rakocy JE, Masser MP, Losordo TM (2006) Recirculating aqaculture tank production systems: Aquaponics—Integrating fish and plant culture, Southern Regional Aquaculture Center (SRAC)

Rakocy JE, Bailey DS, Shultz C, Thoman ES (2004) Update on tilapia and vegetable production in the UVI aquaponic system. University of the Virgin Islands—Agricultural Experiment Station

Schulz K, Weith TH, Bokelmann W, Petzke (2013) Urban agriculture and "green production" as part of sustainable land management, Discussion paper No. 6, Leibniz Center for Agricultural Landscape Research (ZALF) e.V., Institute of Socioeconomy (in German)

Statistical Office Germany (2013) New surveys on vegetable growing in Germany. Online available: https://www.destatis.de/DE/ZahlenFakten/Wirtschaftsbereiche/LandForstwirtschaftFischerei/ObstGemueseGartenbau/Methoden/Downloads/GemueseanbauDeutschland_82013.pdf?__blob=publicationFile, 19 May 2017 (in German)

Stone C (2016) The urban farmer—Growing food for profit on leased and borrowed land. New Society Publishers, Canada

Texier W (2013) Hydroponics for everybody. Online available: http://www.mamaeditions.net/pdf/9782845940871_intro.pdf, 02 Oct 2016

World Commission on Environment and Development (1987) Our Common Future, Oxford. Oxford University Press, New York

Wilson L (2013) Aquaponic system design parameters: Fish to plant ratios, Australia

Woensel L, Archer G (2015) Ten technologies which could change our lives. European Parliament, Brussels