Vertical Farming as an Innovative Solution to Singapore's Food Security Strategy

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Content

1. Abstract

The supply of water, food and energy is essential and vital to humans and yet there are millions of people who have neither one nor the other, people who starve, suffer because of contaminated drinking water or are massively restricted in their development because they have no access to electricity. It is the task of politics and science to create the conditions that most people can enjoy both, an individual resilience against multiple threats as well as a life in cities that can guarantee a secured minimum level of supply.

With the technology of hydroponics, aeroponics and aquaponics, food can be produced in nearly every place in the world without the use of soil and with a minimal use of water. Agrartechnologically, this corresponds to a quantum leap, which has so far been given too little attention. Small self-made or ready-to-go kits could ensure the supply of healthy and fresh food to every family in the developing world. On a large scale, it is the vertical farms and closed recycling loop-systems that can make whole cities more resilient and self-sufficient.

In this paper it is shown how Singapore has chosen an ambitious way to reduce its dependence on food imports and to build up a reliable food security. The unique advantages of various vertical farming techniques are presented, as well as the efficiency of this technology and its profitability as evidenced in individual pilot projects worldwide.

A scientific approach to the concept of resilience is given by a brief overview of current resilience theories. Singapore's urban farming strategy is to be evaluated according to valid criteria of resilience, which again has to be assessed according to the specific characteristics and vulnerabilities of Singapore. Furthermore, it is conceived that the ecological, political, economic and social reality can only be adequately captured in a holistic, transdisciplinary approach that satisfies the distinction between the normative and the pragmatic requirements of resilience, and the fact that resilience is a gradual but not an absolute property.

2. Food Security in Current Research Works

In this paper the definition and requirements of "food security" are taken over from the FAO document on food security on the occasion of the World Food summit 1996:

"*Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life*".[1]

This widely accepted definition covers four dimensions of food security which are food availability, food access, utilization and stability. A distinction can be made between chronic food insecurity associated with structural poverty and low incomes and transitory food insecurity, which can be caused by natural disasters, economic collaps or conflict. In the case of Singapore, the latter represents the real threat for the resource-poor island-state.

Food security is an important part of a city's policy geared at resilience. While stable food supplies from abroad can make a city more resilient against locally caused food shortages due to crop failures or other weather related impacts, sudden severances of supply lines can become an immediate major threat to a city's food security.[2]

When examining the status of a city's food security and its planning inititatives, the central questions are: To what extend must a city (in our case Singapore) be resilient and how can a complex system like a city become resilient?[3]

According to Desouza and Flanery, the planning for resilience to the impacts of stressors within cities requires an evaluation of the vulnerable areas of the city and thereafter a determination of the necessary measurements to reduce vulnerable components and substitute them by more resilient ones.

Based on the assumption that cities are complex adaptive systems, a distinction can be made between physical and social components.[4] Physical components are all the physical resources of a city which it controls or interacts with. The social elements include the inhabitants, institutions and activities.

Vulnerability can be caused by various exogenous and endogenous stressors. Natural threats include natural events such as tsunamis, earthquakes, hurricanes, storms, droughts and tidal waves. For Singapore, bad weather events such as floods, storms and droughts are possible threats against which Singapore must be prepared to. Since Singapore has to import almost all the food, natural disasters in neighboring countries, especially Malaysia, are just as serious threats that need to be taken into account in the action plans of the government.

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[1] http://www.fao.org/forestry/13128-0e6f36f27e0091055bec28ebe830f46b3.pdf, retrieved on 05.2.2017

[2] Stephan Barthel, Christian Isendahl: Urban gardens, agriculture, and water management: Sources of resilience for long-term food security in cities, in: Ecological Economics 86 (2013) pp. 224–234

[3] Kevin C. Desouza, Trevor H. Flanery: Designing, planning, and managing resilient cities: A conceptual framework https://www.researchgate.net/publication/259122914, retrieved on 05.2.2017

[4] Pickett, S. T. A., Cadenasso, M. L., Grove, J. M., Nilon, C. H., Pouyat, R. V., Zipperer, W.C., et al. (2001). Urban ecological systems: Linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. Annual Review of Ecology and Systematics, 32(1), pp. 127–157

Technical stressors, too, can have a profound negative effect on a city's functions and services, on the economy in general and on food security specifically. They can be combined with human stressors such as terrorism, war, crime and riots and their impact can sigificantly endanger the well-being and survival of a city and its people.[5]

Stephan Barthel and Christian Isendahl argue conclusively that urban resilience is highly dependent on a broad diversity of options available to a city in terms of food production and distribution. In this context, the ability to transport and distribute food is an important aspect of the food security system, whose resilience can be strengthened by local proximity of food and water production to consumers.[6] Therefore, Barthel et al. argue, that agricultural production is not the "anti-thesis of the city" but should be - in an ideal case - a fully integrated urban activity as an indispensable prerequisite for resilience. Moreover, urban green spaces need to be protected and memory of how to grow food needs to be supported to link urban people with their life-supporting regional and local ecosystem.[7]

This view is shared by Garcia-Sastre and Kallis, who carry out in their research work that urban agriculture has an enormous potential for resilience building in cities because of its multi-functionality, downscaling to the local production level and the use of empirical knowledge of food production.[8] Urban agriculture and its innovative forms like vertical farming can be a viable strategy to reduce food dependencies of cities who need to be able to function and provide services effectively even under conditions of crisis.

[5] Harrigan, J., & Martin, P. (2002). Terrorism and the resilience of cities. Economic Policy Review – Federal Reserve Bank of New York, 8(2), p. 97

[6] Stephan Barthel, Christian Isendahl (2013), p. 232: "*In complement to the well-known resilience function of long distance trade when harvests fail owing to environmental anomalies and changes, the longue durée perspective applied here shows that urban food security can be built to manage événement chocks by keeping options open for producing and storing food and water in close spatial proximity to the consumers*."

[7] ibid.

[8] Garcia-Sastre, A. and Kallis, G. (2011) 'Building resilience in cities with urban agriculture. A case study for hurricane response in Havana city' in European Society for Ecological Economics, 9th International Conference of the European Society for Ecological Economics: Advancing Ecological Economics Theory and Practice. Istanbul, Turkey, June 14-17

3. Methodological Pluralism

Due to technical and economic globalization, the current economic, social and environmental problems of sustainability are so complex that a single discipline is not sufficient to develop comprehensive solutions. It therefore requires the cooperation of several scientific disciplines and methods to meet the versatility and multi-dimensionality of a research subject.

Although economic, social and environmental sustainability measures can be assessed independently, they interrelate in a complex interacting context. Positive changes in one area can also have negative consequences in another area. This also applies to all resiliency efforts. Something like "resilience" or "sustainability" per se does not exist, only measures and developments that are based on agreed norms and visions.[9]

Modern resilience research uses the methods of engineering, ecology, geography, politics and behavioral science, for the most part based on Holling's distinction between ecological and engineering resilience.[10] Here, reference is made to the different focal points of social sciences and engineering sciences, with the former placing the dynamic aspect and the second the structural aspect at the center of threat analysis.[11]

Also in the field of security research (The American Community and Regional Resilience Institute), a holistic problem-solving strategy is adopted through the creation of a consensus regarding the basic characteristics of the desired resilience: "*Community resilience is the ability to anticipate risk, limit impact, and bounce back rapidly through survival, adaptability, evolution, and growth in the face of turbulent change*." [12]

For the present topic, qualitative methods should be preferred because it is not about significance and falsification but about analyzing the research object from different angles and with different methods. The analysis of ecological strategies and policies which uses theoretical approaches from different disciplines to explain a phenomenon is also called the interdisciplinary triangulation.[13] Such a combination of different complementary methods in the sense of a methodical triangulation can achieve a more adequate understanding of social, political and ecological problems.

Triangulation is also a research strategy with which the weaknesses of one approach can be balanced with the strengths of another approach. Thus, the quality of the research is improved by a higher validity of the research results and systematic errors are avoided through

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[9] Wiesmann, Urs, Messerli Peter, Wege aus den konzeptionellen Fallen der Nachhaltigkeit in: Burger et.al (eds): Recherche dans le domaine du développement durable – perspectives des sciences sociales et humaines. Académie suisse des sciences humaines et sociales, Bern, 2007

[10] Klaus Thoma (ed), „Resilience-by-Design": Strategie für die technologischen Zukunftsthemen, Acatech 2014

[11] Holling, C.S. 1996. Engineering resilience versus ecological resilience. Pages 31-44 in P. Schulze, editor. Engineering within ecological constraints. National Academy, Washington, D.C., USA

[12] Robin K. White, Warren C. Edwards, Ann Farrar, and M. John Plodinec: A Practical Approach to Building Resilience in America's Communities, in: American Behavioral Scientist 2015, Vol. 59(2) p 200

[13] Valerie J. Janesick: The Dance of Qualitative Research Design: Metaphor, Methodolatry, and Meaning. In: Norman K. Denzin, Yvonna S. Lincoln (eds.): Handbook of Qualitative Research. Sage, Thousand Oaks, CA 1994, pp. 209-218, p. 214 f.
Valerie J. Janesick: The Choreography of Qualitative Research Design: Minuets, Improvisations, and Crystallization. In: Norman K. Denzin, Yvonna S. Lincoln (Eds.): Strategies of Qualitative Inquiry. 2nd Edition. Sage, Thousand Oaks, CA 2003, ISBN 0-7619-2691-7, pp. 46-79, p. 67

comparing different data sources of different authors, opinions, theories and methods by using synergistically qualitative and quantitative methods of analysis.[14]

Complex systems like cities can be adaptive, that means they learn from experience which leads to feedback, self-organization and emergence as a spontaneous formation of new properties and structures of a system due to the interaction of its elements.[15] In this case, the use of system theory is self-evident: all elements and attributes in ecologic phenomena are in continous interaction which makes an interdisciplinary approach necessary. Instead of analyzing individual phenomena which never occur in isolation, research focusses on their networking within a given system framework.

A system-based landscape research analyzes the structure, functions and dynamics of the natural environment with its anthropogenic impacts and interactions within an integrated view of the ecosystem, [16] or as Nev Zadeh formulates it: *„To meet the challenges of the emerging information-rich society, landscape ecology must become a holistic problem solving oriented science by joining the transdisciplinary scientific revolution with a paradigm shift from conventional reductionistic and mechanistic approaches to holistic and organismic approaches of wholeness, connectedness and ordered complexity.*[17]

Finally, phenomenology also plays an essential role in conceiving the central issues of this study as well as secondary literature analysis, in which the data are used from other researchers on their own questions. This can be official and non-official data sets as well as data from technical literature. Especially when it comes to ecological concepts based on collectively anchored norms, phenomenological "pre-knowledge" is indispensable to the exploration of mechanisms and cause-effect relationships, or the collection and identification of statistical correlations.[18]

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[14] *"Triangulation always means that one tries to find different solutions for the questioning and to compare the results".* in: Mayring, P.: Einführung in die qualitative Sozialforschung. Weinheim, 2002, p. 147

[15] The theory of comple adaptive systems is a focus of the research work of the Santa Fé Institute https://www.santafe.edu/, retrieved on 4.2.2017

[16] Troll C (1971) Landscape ecology (geoecology) and biogeocenology – a terminology study. Geoforum 8(71), pp. 43–46.

[17] Zev Zadeh: What is holistic landscape ecology? A conceptual introduction, in: Landscape and Urban Planning 50 (2000) pp. 7-26

18 Helmut Seiffert: Einführung in die Wissenschaftstheorie: Bd. Geisteswissenschaftliche Methoden: Phänomenologie, Hermeneutik und historische Methode, Dialektik. München, 1991

4. Challenges to Food Security in Singapore

Climatic changes pose a serious risk to Singapore’s food security. Heavy rainfalls, storms, droughts and floods in the neignbouring country Malaysia directly involves Singapore’s supply with food and fresh water.

Additionally, the rising disposal of waste that is not managed by an integrated solid waste management system for recycling is a big environmental problem for Singapore. More landfilling is not a sustainable option for the island-state because this will cause further soil contamination by waste, pesticides and lead. Plants grown in such soil contain harmful chemical traces that represent considerable risk to human health.

According to the Population White Paper[19], Singapore will have a population of between 6,5 and 6,9 million people by 2030. This means a major challenge to Singapore’s government, to create additional agricultural land, develop land reserves and old industrial areas. Such a population growth also implies higher imports of food and drinking water since land for agricultural use cannot be augmented.

Adequate land management is critical for Singapore’s future: Sufficient land must be provided for housing, manufactoring and services sectors and also for important infrastructure like airports and seaports. The high dependency on food imports render Singapore extremely vulnerable to fluctuations in food supply and prices as well as food safety incidences overseas. A decline in the economies of its major trading partners, a dramatic rise of fuel prices or a major regional crisis with a blockage of transporting routes could have a devastating effect on Singapore’s food security.

At present, Singapore imports almost 90% of its food and less than 1 percent of its land is used for agriculture.The responsible national authority, AVA, introduced on October 2013 a “Food Security Roadmap“ for a resilient supply of safe food which is based on supporting and enabling strategies.[20] AVA uses contract farming in foreign counries (Indonesia, Philippines, Poland, Denmark and China) in order to have a better control of the supply and quality of the food and at the same time, to diversify its food sources. Already, AVA supports innovative farming technolgies like the vertical farming project of Sky Greens, the world’s first low carbon, hyraulic driven vertical farm. It was the investment into this new hydroponic farming techniques that Singapore could increase its local food production by 30%. In the future, if there is not enough space within the city borders, vertical farms could also be established on ships or on off-shore landfill areas like Pulau Semakau.[21]

Another essential component of Singapore’s food strategy is stockpiling. At the moment, a two-month-stockpile is held in government warehouses, but this would be not sufficient in times of crisis. For this reason, Singapore is currently working on developing a common stockpiling concept with its ASEAN partners.[22]

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[19] www.npdt.gov.sg./News: http://npdt.gov.sg./portals/0/news/population-white-paper-exec-summary-english.pdf, retrieved on 8.12.2016

[20] www.ava.gov.sg/files/avavision/issues3-4_2013/food-security-roadmap.html, retrieved on 05.2.2017

[21] http://www.nea.gov.sg/energy-waste/waste-management/semakau-landfill, retrieved on 05.2.2017

[22] Belinde Chng: *“Facilitating a multilateral food stock arrangement could provide opportunities to enhance Singapre’s food resilience*.“in: http://m.todayonline.com/singapore/more-stock-solution-needed-food-security, retrieved on 12.2.2017

Singapore’s Food Security Roadmap proves that the administration is fully aware of the possible risks and threats to the small island-state and the fact that complex emergencies require extensive and conclusive planning for a resilient food system.[23]

It has conceptualized and alread partly implemented a path to greater self-reliance and safety following the recommendations in the UN Report “The transformative potential of the right to food“ by Olivier de Schutter:

“As the competition increases between putting land to urban or to industrial use in the urban and peri-urban perimeter, and as increased food supplies create unprecedented logistical challenges for food distribution and transport systems, it is vital that cities assess their food dependencies, identify weaknesses and potential pressure points and, where possible, develop a variety of channels through which they can produce their food. Urban and peri-urban agriculture, as well as the development of short food chains connecting cities to their local foodshed, will therefore play an increasingly important role.“[24]

[23] Pothukuchi, K., Kaufman, J.L., 2000. The food system: a stranger to the planning field. APA Journal 66 (2), p. 113
In this context, “food system“ can be understood *„the chain of activities connceting food production, porocessing, distribution, and waste management, as well as the associated regulatory institutions and activities.“*
[24] http://www.srfood.org/en/documents, retrieved on 05.2.2017

5. Vertical Farming

5.1. The Imperative of Sustainable Land Management

Nowadays, vertical farming is closely associated with Dickson Despommier from the New York Columbia University, whose book „The Vertical Farm. Feeding the World in the 21st Century“ was first published in New York in 2010.[25] Dickson's ideas build on the suggestions of Cesare Marchetti's, [26] who developed a vision of „garden cities“ as response to the report „The Limits of Growth“, a report for the Club of Rome's project on the predicament of mankind.[27] According to Marchetti, food production should be ensured by indoor agriculture in a closed recycling system that had no further negative impact on the environment.

Although these pioneering ideas were developed in the late 70ies, the urgent need for alternative methods of food production has been widely acknowledged only during the last decade. Since many years, traditional indoor farming has been successully performing the production of strawberries, tomatoes, peppers, cucumbers and herbs. However, all these commerical greenhouses have been horizontal, usually one-story constructions in the outskirts of cities, that consumed land, considerable amounts of water and needed effective transport and cooling systems.

Today, over 800 million hectares - which is about 38% of the total landmass - are used for conventional agriculture and worldwide an additional 10 billion hectares of agricultural land is needed to feed all people (about 7 billion) who will live in cities by 2050. The world's population is projected to reach 8.5 billion by 2030, 9.7 billion by 2050 and exceed 11 billion in 2100, which will require an increase of food production by up to 70%.[28] A change from conventional agriculture to vertical farming should be in the center of a sustainable land management policy, since this agricultural method is based on resource-conserving operation and recycling. Thus, each hectare used for a vertical farm could allow 10-20 hectares to be returned to the natural reserve of green land and forests.[29]

As in the case of tiny island-state of Singapore, where arable land is of poor quality and additional further space for agricultural use is not available, sustainable land use is not a choice but a must. As 90% of all food has to be imported, Singapore can become severely affected by adverse effects on food production in the producer countries. Crop failures, floods, heatwaves, droughts, earthquakes and other consequences of the climate change are permanent threats to an adequate food supply in Singapore.

Vertical farms are the key solution for a sustainable land management in Singapore. They have the potential to make Singapore less vulnerable, less dependent on food imports and – as an ultimate goal – secure a survivability even in times of crisis.

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[25] Dickson Despommier: The Vertical Farm: Feeding the World in the 21st Century.New York, 2010
[26] C. Marchetti: Ten to the Twelfth. A Check on Earth Carrying Capacity for Man (PDF; 361 kB), 1979
[27] https://www.clubofrome.org/report/the-limits-to-growth/, retrieved on 05.2.2017
[28] http://www.un.org/apps/news/story.asp?NewsID=51526#.WJcKTrbhBo4, retrieved on 05.2.2017
[29] Dickson Despommier, 2010

5.2. Characteristic Features of a Vertical Farm

Vertical farming is an innovative, technology-based approach toward food production in a completely controlled environment. The preferred agricultural method is hydroponics, which allows to grow plants without the use of soil, only using mineral nutrient solutions in water. For a most effective way, the production of food without soil with hydroponic and aeroponic farming technologies should take place in specially constructed, multistory buildings.

These vertical farms are immune to weather and other natural conditons that can cause problems to food production. There are no seasons and crops can be grown year-round under selected and fully controlled, hygienic conditions. For each plant, the optimal growing conditions can be created and ensured.

The necessary technology for vertical farms are a constant real-time monitoring and control of temperature, humidity, CO2 concentrations, light intensity and air flow. A natural day-night cycle can be achieved with blue, red and low white LEDs. This special artificial light can bring light directly to the plant where it is needed and it is safer than the direct exposure to sun light and heat. Also, water quality and automated nutrition needs to be permanently controlled.

Vertical farms come as community projects, skyfarming projects or rooftop-farming projects. In a 30-story-high building, renewable energy can be provided by photovoltaic cells, small wind turbines and the incineration of plant waste. The whole production of different vegetables and also fish or poultry can be performed inside one building complex.

5.3. Methods of Vertical Farming

Vertical farms usually adopt the hydroponic method for growing their plants. In contrast to traditional agriculture, a thin stream of nutritioned water runs over the roots of the plants.[30] There are various types of hydroponic techniques like the Deep Water Culture Technique, which is ideal for fast growing plants like lettuce. Here the roots dangle free in the solution and schould not be exposed to sunlight. An air pump supplies extra oxygen.

The Nutrient Film Technique is for plants with a long root system where the nutrient water is continously pumped through sloped channels. A less sophisticated system is the Dynamic Root Floating (also called ebb and flow) which is especially suited for developing countries. Here, the plants' roots are periodically flooded with nutrient water several times a day. In between the flooding, the roots can dry and uptake the necessary oxygen.

Another popular growing method for vertical farms is the Aeroponic System, invented by Richard Stoner in 1982.[31] This technology consumes 70% less water than hydroponics, since only a nutrient-containing mist of water is sprayed onto the roots which are enclosed for keeping the humidity in the root chamber. This system virtually fits to grow any cultivable plant and it uses the least amount of water of all techniques.[32]

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[30] Hydroponics were developed by Willia Frederick Gericke in 1937. Gericke, William: The Complete Guide to Soilless Gardening. London, 1940
[31] https://www.google.com/patents/US4514930, retrieved on 05.2.2017
[32] Dickson Despommier, p. 25

Another method, that is becoming more and more popular and accepted is Aquaponics, a synergistic combination of hydroponics and aquaculture that has no negative environmental impact. Freshwater fish (tilapia, trout, striped bass, catfish and carp) which secrete ammonium are bred in a closed system, where the fish drop is sieved out of the water and then converted in a biofilter to nitrite and nitrate. The nitrat is used for nourishing the plant and the plant waste can be partly used for feeding the fish. With such a system, 7 kilos of vegetables can be produced with one kilo fish.[33]

In Aquaponics, there is no need for additonal fertilizer because the waste of the fish is used by the plants as nutrients.[34] After the water has circulated through the growing plants, it can be transferred back to the fish tanks and only the amount of water used by the plants needs to be replenished.[35]

All hydroponic methods have in common that no expert knowledge is required a priori. The technology is easy to understand and easy to handle. No labor intensive work like tilling, fumigation and watering is necessary, thus considerably reducing the costs of labor.

5.4. Benefits of Vertical Farming

Vertical farms eliminate the need for fossil fuels that would be used for plowing, fertilizing, seeding, weeding and harvesting. For Singapore, which needs to import all fuel, this is an important advantage. The same is true for the improvement of air quality through the presence of vertical farms in the city, that suffers frequently from haze and air contamination due to heavy traffic.

Also, vertical agriculture needs no new farmland and allows the use of renewable energy generation with sun, wind and environment-friendly biomass and waste incinceration. In this way, vertical farming protects the remaining biodiversity and reduces harmful effects on wildlife by reverting land to the natural landscape and restoring the ecosystem functions.

Normal agricultural left-over irrigation water contains enormous amounts of pesticides, herbicides, fertilizers and silt that is polluting and irreversibly damaging the ecological system.[36] In vertical farms, there are no runoffs since all the transpiration water is recovered and re-used in a closed cycle.[37]

The sum of all benefits that vertical farms can bring to its operators, the city, consumers and the environment, are persuasive. A year-round, ecologically healthy food production without weather related crop failures generate completely controlled, safe food without the use of pesticides or herbicides. Faster growth rates and higher yields offer a fast return on the initial investment. The locally grown food brings new employment opportunities, drastically reduces

[33] http://nachhaltiges-landmanagement.de/, retrieved on 2.2.2017

[34] This type of cultivation has been performed in China for thousand years most oft he ties with a Tilapia-Azolla-Rice culture. Tiplapia is a very efficient species of fish, Azolla is a floating aquatic macrophyte tha is eaten by the fish......

[35] Sadikov, 2004. www.dfo-mpo.gc.ca/science/enviro/aquaculture/acrdp-pcrda/Prpjects/reports, retrieved on 4.2.2107

[36] Often human feces are used as fertilizers in conventional agriculure thus spreading hte danger of contamination with infectious germs

[37] According to Dickson Despommier, agricultural runoffs are the world's most destructive source of pollution and has killed hundred of billions of immature crusttaceans, mollusks and fish

transportation miles and experiences greater acceptance among people. They know where their food comes from and this food is fresher and tastes better.[38]

But vertical farming in Singapore has another important advantage, that not only supports the country's food security but also its water security strategy. Some vertical farming techniques use 70% less water than traditional agriculture, and other systems with completely closed circuit systems use up to 90% less water.

5.5. Efficency of Vertical Farming

Examples for successful and profitable vertical farming can be found in cities all over the world, however still at the level of experimental large-scale projects. Indoor farming is also applicable and has been used since decades for chickens, ducks, geese and pigs, although this cannot be called livestock farming under natural, ecological and animal friendly conditions. For this kind of farming, there is still a long way to go to develop acceptable indoor farming conditions for animals that are recommendable without restrictions.

However, growing plants with or without combined aquaculture can be highly successful. For example, the farm of Shigeharu Shimamura [39] who built a farm in 2011 with 25.000 square feet in Japan and produces up to 10. 000 lettuces per day, which is 100 times more per square foot and traditional methods.

Another example is the Green Spirit farm in New Buffalo, Michigan: 10 tons of lettuce are grown in only 500 square feet of space thanks to the very efficient pink-tinted LED lights that radiate just the right blue and red wavelengths for photosythesis.[40]

A different success story is Caliber Biotherapeutics in Bryan, Texas. In a 18-story facility, 2,2 million tabacco-like plants are grown on a space of 150.000 square feet for making new drugs and vaccines.[41]

The list of such profitable pilot projects and big enterprises is long and the possibilities of what you can produce with vertical farms, are far from being exhausted. Vertical farming has the potential to become a central element of a pragmatic food security strategy especially for cities and in our case especially for Singapore. Because not only fruits and vegetables can be produced by this method, but also important basic foods such as cereals and rice. So-called dwarf growth varieties are ideally suited for vertical farming. A 30-story vertical farm on an area of 2 hectares could gain the same yields as the traditional agriculture on 970 hectares.

Researchers have many arguments for this "skyfarming" in green high-rise buildings. It saves space, energy and resources. The food grows directly by the consumer in an environment-friendly manner. When growing rice for example, the rice roots would dangle freely in a

[38] Since the vertical farming allows year-round harvests, productivity is increased by factor 4 to 6, depending on the crop species. For strawberries factor 30!
[39] http://www.ecowatch.com/worlds-largest-vegetable-factory-revolutionizes-indoor-farming-1882004257.html, retrieved on 05.2.2017
[40] http://www.harborcountry-news.com/news/father-of-vertical-farming-shares-views-at-green-spirit-harvest/article_e1f559fe-e58b-5483-beb9-92e89e26ad2d.html, retrieved on 05.2.2017
[41] https://bionews-tx.com/news/2013/05/22/caliber-biotherapeutics-grows-2-2-million-plants-in-pinkhouse/, retrieved on 05.2.2017

nutrient mist in an ideal growth climate and optimal light conditions. Harvesting would be automized similar to a logistics system as in a high-bay warehouse and everything would be processed - food, insulation fiber and biomass.[42] Almost all the problems caused by conventional rices cultivation could be avoided like the enormous amounts of water needed and the secretion of green house gases from the rice fields. With vertical farming, the whole water remains in the building and is only consumed by the growing rice plants. In order to produce one kilo of rice, one does not need 500-1000 liters of water as in traditional agriculture, but only 10 liters.[43]

According to leading biologists, agricultural scientists, ecologists, a city could produce most of its food itself and also recycle most of its waste with clean technologies. Vertical farming projects all over the world have proved the feasibility and profitablity of the vertical farming concept which should be used for urbanization. Singapore has already taken the first steps and endorsed this straegy into its future action plan and food security policy. It synergistically complements its water policy that is oriented towards sustainable water-use and comprehensive water production.[44]

All the necessary modern technologies (photovoltaic energy generation, drip irrigation, lighting technology, phytosanitation, composting) that are required for large scale vertical farming are basically available for Singapore, even if the development in these fields is not far advanced up to now.

5.6. Singapore's First Vertical Farming Project

SkyGreens is a low carbon, hydraulic driven vertical farm, the first one of its kind which won Singapore's Sustainability Award 2014.[45] On 8.6 acres, SkyGreens operates several greenhouses on 30-foot-high vertical frames that yield with its patented technology – according to its chairman Ngiam – five times more food than conventional farming. This includes tiers of growing plants rotating round an A-shaped frame so that the plants receive enough sunlight, irrigation and nutrient on their tour. The rotation itself is ensured through the momentum of flowing water in tiers, so there is only little additional energy used. The rotating structure allows the plants to receive enough sunlight, so only one 40 w LED bulb is needed per 9 meter high frame. Only 0.5 liter water is needed to rotate the whole aluminium structure and this water, primarily collected and recycled rainwater, is collected in an underground reservoir and then re-used.

Another important advantage of the Skygreens technology is its scalability and adaptability to the requirements of any crop. Singapore's Skygreens farm is most probabaly the biggest aeroponic farm worldwide and has been successfully running since more than a decade. It has proved that the ability to grow vegetables without soil makes this farming method optimally suited for a dense, urban setting.[46] Having a population density of nearly 20,000 people per square mile, Singapore is one of the densest countries in the world.

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[42] http://www.swp.de/ulm/nachrichten/wirtschaft/_skyfarming_-reisfelder_-die-in-die-wolken-wachsen-8715716.html
[43] See also the research work of Prf. Dr. Folkert Asch: http://www.asch-online.eu/, retrieved on 05.2.2017
[44]https://www.researchgate.net/publication/228357326_Water_Management_in_Singapore, retrieved on 05.2.2017
[45] www. skygreens.com/ about-skygreens/, retrieved on 05.2.2017
[46] *"While it isn't possible for arable land to be expanded horizontally, an urban farming system could increase production area through vertical externsions of lightweight throughs."* Professor He Jie from the Nanyang Technological University in

As already mentioned, there is also the possibility to build vertical farms off-shore if the urban and peri-urban opportunities are exhausted. The country has a vast water area surrounding it and architects like those at Barcelona-based design firm JAPA have come up with the idea of so-called Floating Responsive Agriculture (FRA) inspired by local floating fish farms that have been used in Singapore since the 1930s.[47]

The design consists of massive L-shaped floating structures that could provide enough space to grow agricultural production. This shape makes the whole system highly efficient**,** maximizing sunlight exposure and minimizing shadows at the same time. Ideally, several FRA towers should be set up at the same time to allow the local population access to sufficient fresh food.

"*We used the sun as a design driver,*" said Javier Ponce**,** principal architect from JAPA. "*The loop shape enables the vertical structure to receive more sunlight without having significant shadows.*"[48]

Singapore. https://www.chinadialogue.net/article/show/single/en/5854-Urban-farming-how-far-can-we-go-in-feeding-cities

[47] http://www.iflscience.com/technology/densely-populated-countries-could-find-food-independence-vertical-floating-farms/, retrieved on 07.2.2017

[48] http://themindunleashed.com/2014/09/floating-vertical-farms-provide-densest-countries-local-food.html, retrieved on 05.2.2017

6. Summary and Conclusion

The summary of the results of the present study allows a conclusive evidence to be drawn about the potentially essential importance of vertical farming technology for the implementation of a sustainable food security strategy. The analysis of current theories on the resilience of cities showed the diversity of partly similar, partly divergent approaches in resilience research. It also became clear that in the development of eco-policy programs to increase the resilience of critical infrastructures, plausible criteria and application-oriented parameters for measuring should be available.

Compared to the resilience of urban services, such as securing mobility, communication or energy supply, the threshold for a critical food supply is easier to determine. The provision of food and drinking water to all population strata should be ensured in the event of a threat so that no persons are affected by restrictions that endanger their health and, in extreme cases, their survival.

The preconditions and features of a vertical farm make this innovative agrotechnology particularly suitable to make a city-state like Singapore significantly more resilient, in case the import of food should be disturbed or blocked for various reasons. Even in such a densely populated city as Singapore, on-shore and off-shore vertical farms can be built, which in the ideal case can even guarantee a self-sufficient supply of food.

The analysis of the Singapore Food Security Strategy has revealed that the responsible authorities are aware of the challenge and have already begun to implement long-term approaches to reduce the vulnerability and improve the resilience of their food security system. With the use of ecologically sound agricultural technology, Singapore aims to implement a pioneering strategy of survival that can serve as a model for other cities in the world that are looking for a sustainable and resilient food supply program.

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