Sustainable Bioenergy
Solutions for Tomorrow

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Saija Rasi, Elina Tampio, Kari Jokinen, Sanna Marttinen, Sirpa Kurppa, Vilja Varho, Jouni Vielma

Resource efficient future cities –possibilities for food production

Solution Architect for Global
Bioeconomy & Cleantech Opportunities

CLIC INNOVATION OY
ETELÄRANTA 10
P.O. BOX 10
FI-00131 HELSINKI,
FINLAND
CLICINNOVATION.FI

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Name of the report: Resource efficient future cities –possibilities for food production

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Summary

Population growth, as well as national and international climate and energy targets and strategies accelerate the transition of urban energy and bioeconomy systems. Changes in urban population will also change demands in housing, health, sanitation services, employment and transportation, along with increasing need of healthy food resources. Urban policy makers must consider that longer the decisions and actions takes, the greater the share of GHG emissions mitigation challenge is ahead. More efficient use of waste and by-products improves resource efficiency in cities, as products like energy and nutrients, stay in functional cities for local use. New technologies (multilayer cultivation, closed production systems, smart management based on ICT, Internet of Things and robotics) enable energy and material efficient food production close to consumers, even in cities. In future, food production in cities will be planned so that the food factories are integrated into urban energy, waste and water systems.

The objective of this report is to gather information about resource efficient options in future cities; what changes in city structures would make biomass utilization and food production more efficient. The aim was also to study integration of biorefinery process in city environment. City farming with energy production from waste materials was selected as example of biorefinery process.

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Helsinki, December 2016

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1 Introduction

About 80% of the rural population lives close to cities in OECD countries (EPRS 2014). In Europe, up to 80% of total final energy consumption can be traced to urban activities (Cerutti et al. 2013). The urbanization is expected to continue in the upcoming decades, increasing the total energy demand and peak demand of energy. Population growth, as well as national and international climate and energy targets and strategies accelerate the transition of urban energy and bioeconomy systems. Changes in urban population will also change demands in housing, health, sanitation services, employment and transportation, along with increasing need of healthy food resources (Besthorn 2012). The classical definitions of the city (beautiful, efficient, and radical) are being challenged by a number of emerging issues. These issues include especially urban husbandry, vertical farming and the creation of new civic spaces, transportation planning, solutions using ICT, green city with efficient recycling, community and health issues and glocalization where cities are both global and local at the same time (Inayatullah 2011).

According to a roadmap of Ministry of Employment and the Economy in Finland, for year 2050 (Työ- ja elinkeinoministeriö 2014), most of the energy systems should have zero emissions in 2050 if we want to achieve the emission reduction goals. This is seen only happening if carbon capture and storage (CCS) systems are taken into practice and operation is commercial. Still, the share of renewable energy should increase and especially domestic bioenergy should be used in all sectors. Besides that, government and municipalities should commit in all actions to promote low carbon economy. Urban policy makers must consider that longer the decisions and actions takes, the greater the share of GHG emissions mitigation challenge is ahead. For example, in China, diversified models and policies associated with urban development have been put forward including the sustainable city, eco-city and low-carbon city models, and urban recycling economy even though the most eco-friendly model is currently not known (Feng & Zhang 2012). Study by Mohared & Kennedy (2014) suggests that even radical scenarios are not sufficient to achieve an 80% reduction in GHG emissions by 2050. Low energy prices are hard to combine with low energy use and high incomes. The only possibility would be an enormous increase in energy efficiency, but such an increase would be unlikely when prices are low (Höjer et al. 2011).

A self-sufficient in energy use and carbon neutral system is the ultimate objective of many cities, which requires efficient use of all available renewable resources. Even though energy efficiency solutions are increasing, new/future city areas are increasingly using wind and solar power as energy sources, but also extensive exploitation of available biomasses is needed to replace fossil fuels. Smart systems enable flexible energy production, adjusted to energy consumption in various locations as well as production of value added products (e.g. chemicals) when there is no need for energy.

More efficient use of waste improves resource efficiency in cities, as products like energy and nutrients, stay in functional cities for local use. Especially production and usage of gaseous fuels (CH_4, H_2) improves city air quality and reduces GHG emissions. It must be noted that waste materials alone can have only small contribution of total energy consumption in cities. In Helsinki, it was estimated that 5% of city vehicles could run with biomethane if biodegradable materials were used for biomethane production (Rasi et al 2012). Similar results on total energy production from waste were gained in Ohio, but added with other renewable energy production; cities can become almost self-reliant on energy (Grewal & Grewal 2013). In terms of biofuel production, algae are more productive per unit area than crops. This is an important consideration for urban areas (Grewal & Grewal 2013).

30% of European cities' ecological footprint comes from food. Part of resource efficiency in future cities is food production in cities, where bioenergy is part of the closed cycles (products → side products → energy and nutrients). New technologies (multilayer cultivation, closed production systems, smart management based on ICT, Internet of Things and robotics) enable energy and material efficient food production close to consumers, even in cities. In future, food production in cities will be planned so that the food factories are integrated into urban energy, waste and water systems. The change in food production systems provides business opportunities to food producers and the systems developers. On the other hand, city farming can bring greater community involvement as citizens can participate in producing their food locally (Besthorn 2012). According to Specht et al. (2014), urban agriculture can be divided to intraurban, where and industry is located within a city or periurban when farming is done on the fringe of a city. It is important to ensure that relevant stakeholders are involved. Generally, this means citizen groups (through community associations or direct citizen involvement), leaders (a cross section of community leaders) and research (empirical research to gauge preferences) and most importantly, companies that are committed to changes. Having all groups involved ensures that the city foresight work is empirically rigorous, democratic, and accesses the best and brightest of the community. The city futures project can be led by planning professionals within the city authority, the university or a foresight association (Inayatullah 2011).

The objective of this report is to gather information about resource efficient options in future cities; what changes in city structures would make biomass utilization and food production more efficient. The aim was also to study integration of biorefinery process in city environment. City farming with energy production from waste materials was selected as example of biorefinery process.

2 Infrastructures in cities

Infrastructure of many cities is old. For example, over a half of global primary energy ends up as waste heat, transport and power generation being major contributors to these losses. To have more resource efficient cities, some of the main changes have to be made to transport, goods deliver, efficient power production and adapted solutions. For old cities, ideal development may be impractical and excessively costly, so targeted and affordable retrofitting is needed. In old cities, focus could be on de-carbonizing the car fleet, improvements to public transport, and micro-scale power generation. Also planning authorities could use planning regulations and incentives to encourage and prioritize in filling of existing infrastructure and districts so that they become progressively more densely populated, rather than continuing to spread the city. That also requires changes in attitudes, as often only sparsely populated areas are currently considered attractive.

New cities or city districts can be engineered from the outset to a compact integrated ideal. Compact cities bring some solutions to transport sector; residents of compact cities have shorter distances to travel to work, shops or other conveniences. Smaller cars, which could be powered by electricity or hydrogen fuel cells, are well suited to these shorter distances. Most importantly, cycling and walking are often the most convenient modes of transport. They also make it easier to establish efficient public transport networks. Moderating demand and using cleaner fuels has a major impact on air quality, one of the big challenges for growing cities.

Distances will also play a more relevant role as cities grow. New technologies and approaches allow food production at the consumption point. In addition, the efficiency of freight transport could be boosted by managing a clear boundary around a city. Major depots on the boundary would become the gateway to the city at which goods are transferred from large inter-city long distance trucks to smaller, more efficient vans within the city. Focusing activity around the depots would also facilitate the introduction of lower emission freight transport, with refueling stations offering, for example, liquefied natural gas (LNG) or hydrogen (CLC 2014).

Different energy, food, waste, and water systems that can have an effect on biomass utilization in the future are listed in Table 1. Some of the systems and/or habits are already in use in many cities but some of them are ideas that may or may not be realized in the future. The list draws from literature and expert consultations. Visions of city infrastructures, where only one (or maximum two) pipelines are used for energy and water distribution is studied (Karaca et al 2013, Karaca et al 2014) but they were excluded from the scenarios as they were seen to be outside of the scope of this study.

Table 1. Systems and habits affecting bioenergy production and/or use in cities.

ENERGY
Smart grids enable flexible electricity delivery from small production units
Increasing teleworking (working at home) decreases traffic / fuel consumption (enabled by efficient telecommunication links)
Renewable energy is used for public transportation
Compact neighborhoods reduce the need of transport/increase the use of public transport
District heating is merged with district cooling
Gas is used more in transport and homes (expanded gas networks)
More gardens, including wetlands, green roof and city farming, are produced decreasing urban island effect and increasing amount of biomass
FOOD
City farming is increasing
Food delivery to homes is increasing
More food circles are established
More online shops for food are used
Food habits change to more vegetarian
Different protein sources
Protein is produced in cities (e.g. chicken, fish, insects)
Food production with 3D printers
WASTE
Waste water and rain water are collected separately
Black and grey water are collected separately
Biowaste is mixed with waste water/sewage
Pre-treatment of biowaste is more effective because of developing technology
Pipe collection systems is used for waste collection
WATER
Rain water is collected and utilized
The amount of used water is decreasing (because of e.g. more efficient water use)

2.1 Examples of new city structures and planning

According to a UNEP (2012) report, in order to be sustainable, a city needs to harness cooperation, political vision and leadership through thematic and/or iconic programs and projects that drive specific sustainability agendas around which integration can be achieved. In addition, cities need to establish sector-specific and institutional strategic intermediaries so that bottom-up participation is enabled. They also need to establish monitoring and evaluation mechanisms, programs and projects that focus on intra and intersector sustainability. Cities also need to make infrastructure choices with the intention of fostering future urban societies that have local flexibility and global linkages (UNEP 2012). An example of option for future resource efficient sanitation system is discussed more detailed in Kinnunen et al (2016). Some examples of different level city decisions, sustainable city planning, or sustainable use of biomass in cities are described next.

2.1.1 One planet living

One planet living is a vision of a world in which people enjoy happy, healthy lives within their fair share of the earth's resources, leaving space for wildlife and wilderness. One Planet Living uses ecological foot printing and carbon foot printing as its headline indicators. It is based on ten guiding principles of sustainability as a framework (Fig 1) (One planed living 2014).

1	Zero Carbon
2	Zero Waste
3	Sustainable Transport
4	Local and Sustainable Materials
5	Local and Sustainable Food
6	Sustainable Water
7	Natural Habitats and Wildlife
8	Culture and Heritage
9	Equity and Fairtrade
10	Health and Happiness

Figure 1. The principles of One planet living.

Examples of Finnish areas which aim at this vision, are the suburb of Kangas in Jyväskylä (http://www3.jkl.fi/blogit/kangasjyvaskyla/) and Kivistö in Vantaa (http://vantaankivisto.fi/fi). More projects from (http://www.bioregional.com/our-work/).

2.1.2 Framework of a liveable and sustainable city of Singapore

The Centre for Liveable Cities (CLC) was established in 2008 by Singapore's Ministry of National Development and Ministry of Environment and Water Resources, with the mission to distill, create and share knowledge on liveable and sustainable cities. Drawing on Singapore's experiences, CLC has developed the CLC Framework for Liveable and Sustainable Cities, a practical framework to developing high-density, highly liveable cities (CLC 2014). The results of this framework are that the city has a high quality of life, competitive economy and sustainable environment (Fig 2). These objectives require integrated master planning and development; thinking long term, 'fighting productively', building in some flexibility, effective execution, and systematic innovation. In addition, dynamic urban governance should lead with both vision and pragmatism, build a culture of integrity, cultivate sound institutions, involve the community as stakeholders, and work with the markets.

Figure 2. Liveable and sustainable city.

2.1.3 Stockholm

In Stockholm the planning of sustainable urban development started at 2007, when a strategic project, Vision 2030, was launched. Strategy included e.g.

1) Reusing developed land (brownfields)
2) Locating new development areas with good access to public transportation
3) Respecting and enhancing the character of the city, for example, the cityscape, the built environment, and the green structure
4) Redeveloping semicentral areas and transforming industrial areas into urban areas of mixed uses characterized by variation
5) Establishing focal point in the suburbs
6) Meeting local demand and
7) Developing public spaces.

The first actions were taken in the area of Hammarby, where environment and infrastructure of the area was planned by the Stockholm Water Company, an energy company (Fortum) and the Stockholm Waste Management Administration. The Hammarby model (Table 2) is an example of how city structures can be changed towards a sustainable direction with good planning.

Table 2. The Hammarby Model.

City structure	Action
Building materials	Environmental considerations apply to all materials, whether used visibly in facades, underground, or internally. This includes structural shells and installed equipment. Only sustainable and tested eco-friendly products are used. Potentially hazardous materials, such as copper and zinc, are avoided to prevent leakages of unwanted substances into the environment.
Water and sewage	Storm water is unconnected to sewerage systems to improve the quality of wastewater and sludge. Rainwater from streets or nondomestic storm water is collected, purified through a sand filter, and released into the lake reducing pressure on the wastewater treatment plant. Rainwater from surrounding houses and gardens flows through open drains to the channel. This water runs through a series of basins and then to the lake. Hammarby Sjöstad has its own wastewater treatment plant built to test new technology. Four new and different processes for purifying water are currently being tested.
Biogas	Biogas is produced in the wastewater plant from the digestion of organic waste and sludge. The wastewater from a single household produces sufficient biogas for the household's gas cooker. Most biogas is used as fuel in eco-friendly cars and buses.
Green spaces	Roofs covered in stonecrop or sedum plants are attractive to people. In addition, the plants absorb rainwater that would otherwise drain into the sewerage system, adding pressure on the wastewater treatment plant. Moreover, the region has carefully preserved oak forests, green areas, and other planted trees help collect rainwater instead of draining it into the sewerage system. This vegetation also ensures cleaner air and balances the dense urban landscape.
Waste	Combustible waste, food waste, newspapers, paper, and other discards are separated and deposited in different refuse chutes in or adjacent to buildings. The refuse chutes are linked to underground vacuum-powered pipes that lead to a central collection station. An advanced control system sends the waste to large containers, one for each waste category. Refuse collection vehicles thus collect the containers without driving into the area, and refuse collection workers avoid heavy lifting.
District heating and cooling	Treated wastewater and domestic waste become sources for heating, cooling, and power. A combined heat and power plant uses domestic waste as fuel to produce district heating and electricity. Wastewater from the treatment plant fuels the production of district heating in the Hammarby heat plant. Cooled by heat pumps, the treated and cooled wastewater may also be used in the district cooling network.
Electricity	Solar energy is transformed into electrical energy in solar cells. The energy from a single solar cell module covering one square meter provides around 100 kilowatt-hours per year, which is equivalent to the energy used by three-square meters of housing space. There are solar panels on many roofs used to heat water. Solar panels on residential buildings often provide sufficient energy to meet half of the annual hot water requirements of the buildings.

3 Example: Future cities in Finland

The increasing use of bioresources in Finland is considered here through three scenarios discussed in workshops (Table 3). In all of them, it is assumed that bioresources will be used in future in cities more effectively but the level of usage depends on decisions made in cities and by consumers. The economic impacts are not taken into account; the scenarios are examples of impact of city structures and more careful planning with economic calculation is needed.

3.1 Background for the scenarios

The population forecast for year 2030 in Finland is over 5.8 million and a share of over 65 years old will increase to over a fourth. A clear change is also happening in global demography when average age in industrial countries increases while increasing population in developing countries is very young. This has already increased unemployment in many developing countries, which may increase global security risks.

Energy consumption in Finland in 2030 is lower than today but the share of electricity from total energy consumption has increased. End use of energy decreases because of increasing energy efficiency e.g. in transports and buildings. Landfill directive (from 2016 forward) (VnA 331/2013) is one of the drivers for more effective biowaste utilization. Prices of food and energy have risen, creating more business opportunities to bioenergy / biorefineries. Working at home is more accepted and used, neighborhoods are more compact (new areas) and planned with good public transport and cycling infrastructure. Use of electric vehicles will increase. The heating loads will diminish, whereas cooling loads will increase (Orehounig et al. 2014).

Global drivers for change are e.g. population growth, decreased biodiversity and limited food production, need of uncontaminated water and clean environment; all of them have an effect on food production and consumption. Crop and animal production will change and is carried out in different places and with different technologies than at the moment. Changes in lifestyle and social innovations are also drivers in future. Consumer citizenship is increasing; consumption patterns affect human development and sustainability. People are increasingly seeing themselves as citizens first and consumers second (McGregor 2002). Whole system forms industrial and socio-ecologic closed loops. Changes in consumer behavior will have the largest impact as consumers are using products in a different way and moving from products to services is increasing. Consumers'/citizens' participation will increase and they will own natural resources in different ways (Hietanen et al. 2014).

Residential areas will be interspersed with 'productive areas', containing food production areas as well as manufacturing and office facilities. With increasing transport prices downtown locations are more interesting even for traditional agricultural activities, and citizens will require basic needs to be covered at locations closer by. As cities grow to areas that were previously used for agriculture, some of the agricultural production will remain and the town grows around them. This is already happening in Helsinki (Viikki) and Seinäjoki (e.g. http://www.kokkaamo.fi/porsastilat/tilat/aittomaen-tila/).

Home space will become smaller in city areas, and in multi-purpose usage. As cities grow, real estate value will increase, and hence property prices will rise quicker than salaries. Therefore, families have to live in smaller apartments and houses than is currently the case. Smaller homes will additionally require less energy per person. Consequently, the cities' residential areas will become densely populated, but at the same time, their energy consumption will remain overall stable despite the increase in population.

3.2 Scenario I: Business as usual

Scenario represents a continuation of current planning and policy concerning density and urban form, meaning there is no big changes in policy or habits in energy use or food consumption. Food spill goal has not been achieved, i.e. the amount of food waste is at the same level as in 2010. In addition, biowaste collection rate is in same level as 2010. Some changes do happen because of e.g. European policy and the technology development. After 2020, only zero-energy houses are built but its effect on total energy consumption is small (as buildings are renewed at a slow rate). New compact living areas in cities as well as increased working at homes are decreasing the energy use in transportation. New shopping habits, e.g. using online shops, home deliveries and food circles (local food circles), are decreasing the food waste as buying food is more planned but it has only small effect on total amount of food waste as food waste prevention is not well promoted by cities or government. The main electricity production comes from nuclear power.

The main obstacle of utilizing biodegradable waste material from city area is the efficiency of separate waste collection. In Helsinki area, only 43 % of municipal biowaste is separately collected while industrial biowaste about 75 % is collected (Rasi et al. 2012). Waste incineration has increased after year 2016 because of landfill directive and because of low biowaste collection rate, 57 % of biowaste is also incinerated. However, because of the technology development, the separately collected biowaste is more effectively treated in treatment plants and it has increased the profitability of biowaste treatment plants.

In new building areas, rainwater from streets or nondomestic storm water is collected (separately from wastewater), purified through a sand filter, and released into the lake/sea. In old areas, rainwater is still collected with wastewater and wastewater treatment plants have not increased the efficiency of wastewater treatment.

3.3 Scenario II: Recourse efficiency city planning

In this scenario, similar decisions are made as, for example in Kalasatama, Helsinki. City planning has a goal for resource efficiency with long-term thinking and it is practiced in new living areas. Options which are technically easy to apply (Table 3) in city systems have taken into practice also in old living areas. Number of vegetarians has increased because of the awareness of decreasing resources. Small-scale energy production is promoted with tax reliefs and changes in laws so it is easy for any producer to provide energy to local distribution networks. A central enabling factor was the development of the so-called smart grids.

Cities use only renewable energy, biomethane, biodiesel, bioethane and/or electricity, in city transports. Renewable energy is produced from city biomass materials but also biomass from surrounding areas. Gas networks are expanded and the use of gas is increased. Biomethane distribution in natural gas networks has increased because of increased biomethane production. In new areas, district heating is combined with district cooling improving energy efficiency, enabling e.g. cooling of grocery shops and collection of waste heat from buildings.

Rainwater from streets or nondomestic storm water is collected (separately from wastewater) in new building areas and it’s planned for some older areas as well. Rainwater is purified through a sand filter and used e.g. for gardens and decreasing the use of pure water. The efficiency of wastewater treatment plants has increased because of technology development and energy efficiency of the treatment plant has increased because of good planning and as some of the sewage is treated with biowaste increasing the energy production.

Food spill goal (-30% from 2009 level) is achieved. In all new areas, the pipe collection of waste is used and it is planned to some old areas as well decreasing the transport in these areas. Technology development also enables better sorting of biowaste increasing the biowaste collection rate. Separate waste collection rate in households has increased to 65 % and in industry to 90%.

3.4 Scenario III: Maximized use of bioresources

In scenario III city planning is based on maximal use of resources and planning is done relevant with stakeholders are involved. Industries have increased their energy efficiency remarkably. Because of the development on rooftop-based distributed photovoltaic systems, almost 30 % of the city’s annual electricity consumption is supplied by solar energy (Byrne et al 2015). Big changes in city structures are done also in old areas. Food habits have changed; diet includes more plant based carbohydrates and protein and new protein sources are accepted (as insects, synthetic meat etc.). Food spill goals are achieved (-30% from 2009 level) and separate waste collection is effective and collection rate of 65 % is achieved in households, 90% in industry.

Amount of distributed energy (and number of plants) has increased. Technology development in energy solutions increases energy efficiency and the share of renewable energy. Maximal use of waste materials is planned in biorefinery processes, e.g. different fractional processes are used before energy production.

Wastewater treatment technologies have changed because of the separate collection of black and grey water. Grey waste treatment is done closer to settlement areas and used for irrigation and/or released in lakes/sea. The share of dry toilets is increased because of the technology development (dry toilets are more easy to use also on city areas) but also because of changes in waste fees (high costs for black water collection).

New protein sources (laboratory beef, algae, cellular growth based on fermentation) are used because of technology development, changes in attitudes and increased production cost of traditionally produced meat. Protein production is also done in cities as changes in city structures enable e.g. fish production in ground floors of buildings and/or poultry and egg production in block buildings (where whole building is meant for meat production). The use of insects based proteins has increased due to the expending insect production in cities.

Greenhouses on the rooftops are common view in city areas. Approximately 30 to 35 greenhouses with the size of 5000 m^2 are needed to produce tomatoes and cucumber for the population in Helsinki. Moreover, smaller greenhouses are there to produce various lettuce varieties and herbs. Vegetable waste is treated in biogas plant and nutrient from digestate is used in greenhouses.

Table 3. System changes in different scenarios.

Scenario	General development path	The main changes in city systems		
		Energy	**Food**	**Waste and waste water**
I **Business as usual**	Scenario represents a continuation of current planning and policy about density and urban form. No big changes in policy or habits in energy use or food consumption. Food spill goal has not achieved. Biowaste collection rate remains at the 2010 level	• New compacts living areas reduced the need of transport/increase the use of public transport • Increased working from home decreases traffic / fuel consumption • After 2020 only zero-energy buildings are built	• Food delivery to homes has increased • More food circles • More online shops for food	• Waste incineration is increased (including biowaste that is not separately collected) • Pre-treatment of biowaste is “more” effective at treatment plants because of technology development • Waste and rain water are separately collected in new building areas
II **Resource efficiency city planning**	City planning is head to resource efficient point of view with long-term thinking and is practiced in new living areas. Easy options in city systems have taken into practice also in old living areas. Share of vegetarians is increased. Food spill goal (-30%) is achieved. Separate waste collection is more effective in homes and collection rate of biowaste has increased to 65 %	• Same as I + • Smart grids enable energy production from small plants • Small-scale energy production is promoted with changes in taxation etc. • Renewable energy (electricity, gas, biofuels) are used in public transportation • District heating is merged with district cooling • Gas networks are expanded • Gas is used more effectively in waste water treatment plants	• Same as I + • Urban farming has increased (both home and commercial) reducing transport need and increasing self-sufficiency (of cities) • Indoor farming has increased	• Same as I + • Waste and rain water are separately collected also in old areas improving the waste water treatment and rain water is used for gardens etc. reducing the use of pure water • Increased use of pipe collection systems for (separately) collected waste decreasing traffic in new areas • Biowaste is mixed with sewage (treated in same processes)
III **Maximized use of bioresources**	Big changes in city structures are done also in old areas. Food habits has changed (new protein sources are accepted). Food spill goals are achieved. Separate waste collection is effective and collection rate 65 %	• Same as II + • Distributed energy sources has increased • Technology development in energy solutions increase energy efficiency and share of renewable energy (solar and wind) • Industrial energy efficiency has increased	• Same as II + • Protein in produced in cities (chicken, fish, insects) • New protein sources; laboratory grown beef, algae, cellular growth though fermentation • Novel and efficient hydroponic systems are utilized	• Same as II + • Black and grey water (and rain water) are separately collected • Share of dry toilets are increased (drying and freezing systems) • Maximal use of waste materials in biorefinery processes

4 Food production possibilities in cities

Urban agriculture is the future concept for the production of feed and food. Agriculture as term means both the animal farming and farming of plants, which can also be executed in city scale. Urban agriculture is located in the fringe of a city (van Veenhuizen 2006) and it increases the food self-sufficiency of the city. Food farming in cities also decreased the transportation distances, e.g. food miles and its CO_2 emissions. For example in the USA the average food delivery is 1640 km, and for total supply chain 6760 km, where beverages have shortest distances, meat products longest (reviewed in Specht et al. 2014).

The urban farming can be seen as a distributed system consisting of different alternatives and scales for food production from the individual and communal farming concepts to the controlled and commercial applications. It is related to limited and highly competed availability of space, closeness to the markets, use of urban resources (e.g. wastes) and high degree of specialization. More advantages are gained if the food production can be connected to other urban activities, e.g. with waste management and energy production. Using all the city resources effectively, all the produced side-products can be used as raw material for another process. For example, black and grey water can be used for irrigation and solid waste and plant material can be used for energy production. In addition, all biomass streams can be used as a source of nutrients. Market value comes from closely produced food; organic food and local distribution and transportation networks (Besthorn 2012).

Urban agriculture is dependent on the urban resources, labor, consumers and policies applied. Urban agriculture has different aims and resources in developing and in developed economies, where the space is the most limiting factor and the circulation of different biomasses is essential. Different systems can include plant (rooftop farming, hydroponics, vertical farming) and/or animal production (aquaponics, insect farming), which aim to maximize the use of space in the city area (van Veenhuizen 2006). Table 4 represents the different locations of different urban food factories and their interaction/control with the surrounding environment. The urban agriculture mainly consists of the production of plant materials within the city, thus the farming of insects is also described in this report.

Table 4. Types of urban agriculture and the spatial location and control of the system (based on http://www.pauldegraaf.eu/downloads/RvSL_Summary.pdf and http://www.ruaf.org/sites/default/files/p3-12.pdf)

	Open	Mixed	Controlled
Building	Microclimates in and around the built environment (mushrooms and vines)	Rooftop gardens (vegetables)	LED light cabinets (vegetables) Urban livestock (rabbits) Aquaponics
Inner city	Permaculture gardens (vegetables, fruits, nuts, roots) Urban livestock (bee keeping)	Kitchen and community gardens (vegetables) Urban livestock (chickens, sheep)	Urban livestock (worms, insects etc.)
City fringe	Forest gardens	Market gardens (vegetables)	Greenhouse nursery (vegetables)
Periurban	Agroforestry (fruits and nuts) Extensive livestock (beef, cattle, sheep) Ecological restauration	Mixed farming (livestock, staples, vegetables) Semi-intensive livestock (dairy)	Greenhouses and precision farming (vegetables, staples) Intensive livestock (pigs, poultry)

4.1 Communal farming

One form of the urban agriculture and probably the most common form is communal farming. Communal farming unites the privately and communally owned spaces and gardens, which are collectively tended by people who own either individual or shared farming plots. Communal gardens can also occupy unused spaces in cities and increases the greening of urban landscapes (Sanyé-Mengual et al. 2016). The aim of communal farming is to supply fresh food to the users, but also the economic, social, cultural, environmental issues have become more and more important as the awareness of the communal farming has increased. Additionally, communal farming is a part of the food security of the cities (reviewed in Mok et al. 2014, van Veenhuizen 2006). Despite the small size of individual communal farms, the total amount of produced food can be very high, similar to the production in rural farms. This may be due to e.g. the reduced amount of insects and pests in city areas and due to the efficient manual tending (harvesting, fertilization, watering) of the farms by the community individuals.

4.2 Rooftop farming

Rooftop farming increases the synergies between agriculture and urban buildings by utilizing the unused roof space of buildings. Additionally, the rooftop farming can be connected with the energy and nutrient flows from the building to increase the effectiveness, self-sufficiency and economics of the farming. Rooftops can be farmed either as open systems or similar to greenhouses (Figure 3). Furthermore, different technologies can be applied, e.g. soilless cultivation in hydroponics systems. Rooftop gardens also acts as a rainwater and nutrient capture and recycling system enabling also the recycling of biowaste. In addition, the gardens can be integrated with the buildings' energy systems to save energy and provide ventilation and cooling to the building (Buehler & Junge 2016, Specht et al. 2014).

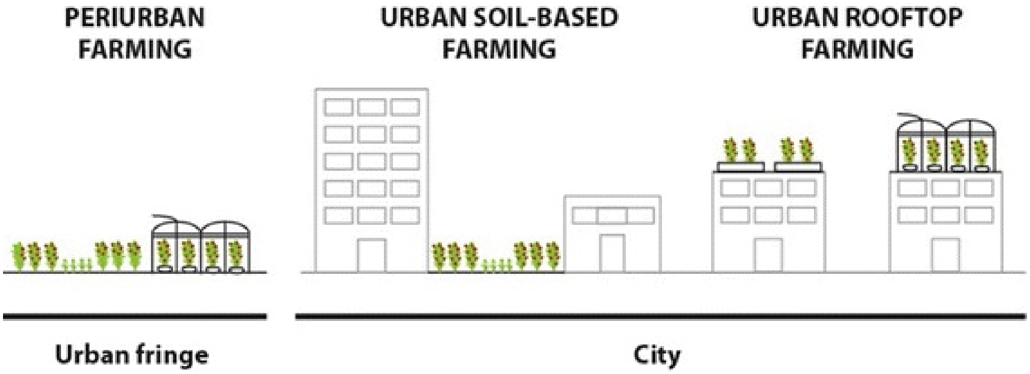

Figure 3. The spatial location of urban rooftop farming in cities (Sanyé-Mengual et al. 2016).

Rooftops can be intensively farmed to produce e.g. vegetables, roots, tubers, salads and herbs in small space. According to FAO, one square meter of micro garden such as rooftop garden can produce any one of the following:

- around 200 tomatoes (30 kg) a year
- 36 heads of lettuce every 60 days
- 10 cabbages every 90 days
- 100 onions every 120 days

The same garden consumed around 1000 liters of water per year (<3 L per day), which can be achieved with roof of 10 m^2, which collects 1000 L of water for every 100 mm of rainfall (FAO 2015).

Nowadays, rooftops, if farmed, are not aimed for consumption as they are more commonly used in the management of storm water run-off (Specht et al. 2014, Mok et al. 2014). Rooftop applications for the production of food in urban environments are still very much a novelty, thus, there are both commercial-scale and community-focused projects in existence, as well as household-scale rooftop gardens (Mok et al. 2014, Buehler & Junge 2016).

4.3 Controlled environment agriculture

Controlled environment agriculture (CEA) i.e. indoor farming, has evolved into a commercially viable option for food production in urban and semi-urban areas with a help of LED lights and computer assisted control systems monitoring the growing conditions (like pH, temperature etc.). Compared to traditional farming, CEA does not produce agricultural runoff, it allows year around crop production and it uses less water than traditional farming. In addition, the production is protected from adverse climatic events. It can also be located in urban areas, as it does not rely on soil availability (Despomier 2013).

In controlled environment, the benefits are e.g. the flexibility to grow crops at any geographical locations, reduced pesticide use, the decrease of food miles (reduced distance from farm to consumer) and possibilities in urban symbiosis (material and energy flows). Recent studies are focusing on challenges relating to the design and operation, i.e. energy requirements, different ways to deploy artificial LED lighting, dehumidification and the monitoring of crop reactions to the changes (Goldstein et al 2016, Tsisimpelis et al 2016).

4.3.1 Hydroponics

The hydroponics as a matter of urban farming technology unites plant farming with water circulation. Technology is based on the absence of soil, which minimizes the land area needed to grow plants. Additionally, compared to conventional farming, hydroponics need less labor, external inputs and time but are often characterized with higher investment and management costs. In hydroponics, the plant roots are submerged in flowing water, which circulated nutrients to the plant. Important parameters in the operation of hydroponics are the temperature, humidity, CO_2 level, light intensity, ventilation and the plants nutrient need (van Veenhuizen 2006). The hydroponics farming can be cooperated as a part of rooftop farming to exploit the synergies from the building, e.g. energy and nutrient flows (reviewed in Specht et al. 2014).

4.3.2 Aquaponic production

Aquaculture is the fastest growing sector of agriculture. While the largest potential for volume growth is in the offshore farming of the oceans, recirculation aquaculture systems (RAS) are becoming a true alternative for sustainable production in controlled environment with limited effluents. Due to sparse use of new water, efficient space use, and possibility to treat wastewater, RAS farms can be placed within industrial or even urban areas. Aquaponics is defined as a combined production of fish (aquaculture) and vegetables (hydroponics). In aquaponics productions, water, nutrients, and heat energy can be recycled thus offering an interesting concept for low-impact food production. These systems could be further integrated into “sustainable aquatic cycles” with biogas plants and micro algae bioreactors (Kloas et al 2011). However, while even RAS farming is still yet to prove to be economically viable in the production of medium price fish species such as rainbow trout or Atlantic salmon, most aquaponics systems are still either in experimental or start-up phase. More information on the technology and business cases can be followed at the newly established web pages of COST project on aquaponics (https://euaquaponicshub.wordpress.com/).

An example:
On average, 20 000 people are consuming salmon annually about 180 t in Finland. If 10% of this (18 t) is produced locally, it would require that 20 t of fodder is either transported to city or produced locally. Amount of fish waste would be about 8 t/a and with normal recirculation aquaculture system energy consumption would be about 36 MWh. The amount of energy in fish waste (8t/a) is about 6 MWh, and nitrogen, phosphorus and potassium amounts about 135, 515 and 22 kg/a, respectively. The energy production from fish waste would cover the amount of energy needed for nutrient recovery (from fish waste).

4.3.3 Vertical farming

Vertical farming the form of CEA that include high-rise, multistoried buildings where e.g. fruit, vegetables and grains are raised (Table 5). The floors are usually designed to accommodate certain crops using hydroponics (water with nutrients) (Al-Shalabi 2015). In vertical farming, it is important to evaluate, the overall carbon footprint and how much energy is needed to power such a building. There is not many research made from vertical farming and energy usage but according to studies by Al-Chalabi 2015, the carbon footprint can be higher in vertically grown products than with conventional grown, if the buildings energy consumption is produced with traditional energy. In areas with abundant sunlight, the building can generate enough energy by solar panels to meet the requirements for lighting and water pumping. Further research is required on energy issues with vertical farming.

Table 5. Vertical farms in different countries (Despomier 2013).

Location	Details	Location type
South Korea	Three stories tall Experiments Uses grow lights	Rural
Japan (several)	Half use sunlight and the others use grow lights Many are commercially successful	Peri-domestic
Singapore	Commercial Four stories tall Uses sunlight	Inside the city limits
Chicago	Three stories Non-governmental organization Uses grow lights	Inside the city limits
Chicago	Commercial Uses grow lights	Inside the city limits
Vancouver	Uses sun light Four stories tall	Inside the city limits

4.3.4 Insect farming

There has been recent development in the field of insect farming for the production of edible protein for direct human consumption as well as for the indirect use. Insect farming contribute to food security, as they are nutrient and protein-rich and can be used as replacement for other protein sources, e.g. livestock farming. The farming of insects does not directly compete with the production of other human food as the insects can be grown on different waste/side streams, for example on biowaste as a part of a biorefinery system. Insects species used in food production have high reproductive rates, the production is relatively easy to manage, and the farming does not need in-depth training. Insect farming has low greenhouse gas emissions and a very low land area need compared to conventional farming. Insects also are very efficient in converting feed into food (see Table 6) (FAO 2013).

Table 6. The effects of insect farming in relation to conventional livestock (beef, pig, poultry) farming (based on FAO 2013).

	Beef	**Pig**	**Poultry**	**Insects**
Edible part of animal (%)	40	55	55	80
For production of 1 kg				
Feed conversion (%)	10	5	2.5	1.7
GHG emissions (g per kg of mass gain)	2700	-	500	<100
Water use (L)	22000-43000	3500	2300	Lower
Land use (m^2)	150-250	50-75	40-50	20
Energy use (MJ)	175-275	100-225	75-150	170

- not available

Insects can be farmed in indoor environments, even in households near the consumer, which subsequently reduces the transportation need. In fact, insects are the only livestock that can be efficiently farmed in urban conditions. In temperate and cold climates, the farming in indoor conditions is even mandatory to provide sufficient growth conditions for the insects and to maximize the production with optimization of conditions. Like vertical farming, also insect farming can utilize vertical and other underutilized space in cities (Dossey et al. 2016).

Interest as a protein source for human consumption and as a feed has grown rapidly. In parts of world the eating of insects has not been common, the attitudes and legislation is still changing thus the overall direction is the increasing consumption and farming of insects. Thus, there are still lessons to learn in the optimization of the insects farming in automated systems related to the dietary needs of different species and the growth cycles (Dossey et al. 2016).

In Sweden, a project aims for the self-sufficient production of proteins by insects farming in the city of Stockholm. It has been estimated that the population in Stockholm in 2018 will be around 950 000 inhabitants, which annual consumption of meat requires 500 000 m^2 of farmable surface. The project proposes construction of nine urban insect farming systems, that each will offer around 10 000 m^2 of farmable surface for crickets farming. The farming system includes all the production stages from the eggs to the adult insects (Belatchew 2014). There are also commercial companies in Europe that produce insects, insect protein products, and different companies have also visioned different scale farming applications also to households.

4.4 Pig city

An example of new idea in food production was developed in Denmark. The idea won an architecture competition organized by RealDanian (http://www.realdania.org/) and the building is under planning. The idea was to combine pig farming and tomatoes market gardening in a way that diminishes many of the serious consequences for people, animals and the environment that are normally associated with modern, industrial farming. The symbiosis project demonstrates how industrial agricultural production can combine animal, human and environmental welfare with increased profitability for particularly greenhouse production, which is suffering from the rapidly increasing energy prices.

In this model, pig farming is on the ground floor and tomato plantation on the first floor. The building is planned to be placed in a hollow making it invisible in the landscape, and therefore making it possible to be built e.g. inside cities. Housing for employees will be located at the higher floors. Despite the size of the facility, it appears concentrated, simplified and open to the public, with a service area encompassing a farm shop and a classroom. The building gives the public the opportunity to get very close to a model food production, and this will benefit the image of agriculture in the public eye.

The holistic farm concept aims at producing food with markedly reduced CO_2 emissions. The waste products of the pig farm, such as nutrients, CO_2 and body heat, are to be used directly in the market garden, which is transformed from being very energy-intensive into a zero-energy solution. A biogas plant, which treats slurry, animal waste and catch crops from the slurry emission area, supplies energy for the production and electricity to the national grid. The overall energy account shows a significant profit, and the CO_2 balance is equally positive (Pig city 2010).

5 Example: city farming

Because of the change in food habits, local food is favored, which has increased the amount of home farming but also commercial farming in greenhouses in city areas. Greenhouse production in city areas can be sustainable if the use of biomaterials is also resource efficient. The aim of the production is that the greenhouse vegetables are produced to local people reducing transportation and improving the products quality. Vegetable waste, as well as other biowaste from the area can be treated in biogas plants and the energy and the nutrients can be used for local production (Figure 4).

The aim of the city farming example was to compare different size greenhouses (3000 and 5000 m^2) aimed to produce vegetables (tomato and cucumber) for the city inhabitants. The vegetable residues are treated in a biogas plant, which energy and nutrient flows were assessed. A greenhouse with the size of 3000 m^2 is able to produce vegetables for 10 000 people (tomatoes for 8 400 and cucumbers for 17 000 people). With bigger greenhouse, the production capacity increases to 14 000 and 28 000 people, respectively. Utilizing modern technology the greenhouse is carbon neutral and economically viable. In summer, the greenhouse will also collect heat to be utilized for warming up the service water in local houses and the use of LED lights saves electricity consumption. The greenhouse(s) can also be built on the roof of a building and thus maximizing the solar capture. The biogas plant also provides an opportunity to nutrient recycling as amount of nitrogen and phosphorus from biogas plant digestate can be used for tomato and cucumber production and other fertilizing purposes.

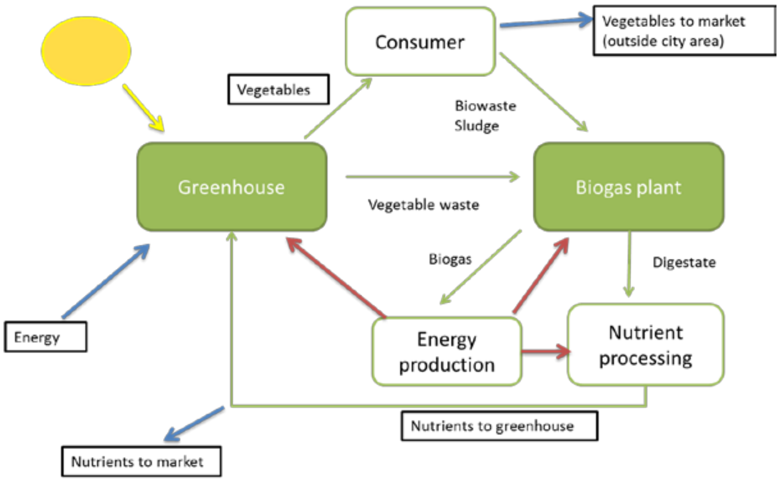

Figure 4. Description of eco-efficient commercial greenhouse (edited from Pesola et al 2012).

5.1 Materials and methods

The combination of a greenhouse with the size of 3000 and 5000 m^2 with a biogas plant was analyzed (Scenario 1, Figure 5). First, the amount of vegetables produced in the greenhouse was calculated based on the average production of tomatoes and cucumbers (Jokinen 2015a). The nutrient utilization of the vegetables was based on the average fertilization practices in Finland (Table 7). Secondly, the amount of nutrients transported from the greenhouse to the biogas plant was calculated based on the production of the residual vegetable biomass in the greenhouse and its characteristics (Table 7). The energy consumption in the greenhouse was calculated in two scenarios, where BASE scenario consisted of the current practices in commercial greenhouse production (high heat and electricity use) and LED scenario represented a future scenario with lower energy use due to use of led lights and heat recirculation. The energy consumption values (Table 8) were based on Kaukoranta et al. 2011. Additionally, a scenario, where the municipal biowaste were utilized within the biogas plant, was assessed (scenario 2). The biowaste production was based on 10 000 inhabitants' waste production (Table 7). The biowaste was assumed to be utilized as a co-feedstock in the biogas plant, along with the vegetable residues from a LED scenario greenhouse to increase the energy and nutrient production.

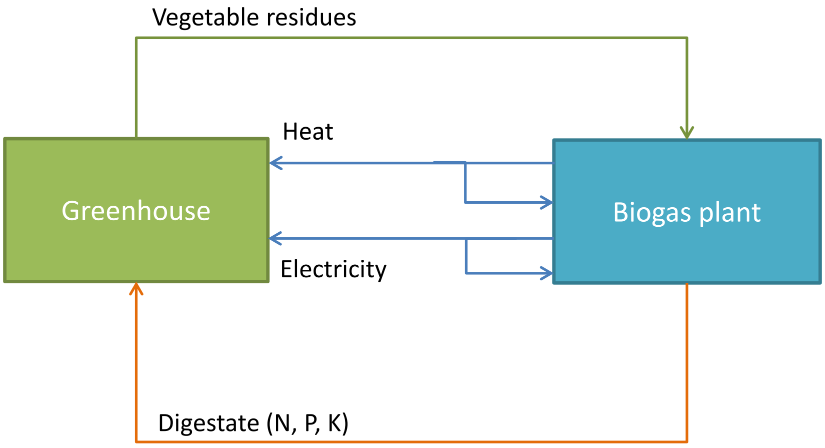

Figure 5. Simplified scheme of the combination of greenhouse and biogas plant with energy and nutrient circulation (Scenario 1).

Table 7. The production and characteristics of the greenhouse vegetables, their residues and municipal biowaste.

	Tomato	Cucumber	Biowaste[a]
Production (kg/m^2/a)	67	112	80.3
Nutrient utilization (kg/m^2/350d)			
N	0.35	0.40	
P	0.09	0.07	
K	0.56	0.55	
Residual waste (% of harvest)	24	27.6	
***Residue characteristics*[b]**			
TS (%)	11	9.05	30
VS/TS (%)	85	93.9	87
N (%TS)	2.3	2.18	2.5
P (%TS)	0.18	0.18	0.4
K (%TS)	2	2	0.9
CH4 production (m^3/tVS)	320	260	500

[a]kg/cap

[b]based on Kinnunen et al. 2016.

Table 8. Energy consumption of greenhouses and the possible nutrient processing after digestion.

Energy consumption	Heat	Electricity
BASE scenario (kWh/m^2)	300	1450
LED scenario (kWh/m^2)	200	950
Digestate separation and ammonia stripping (kWh/t/a)	41.8	8.21

The figures used in greenhouse calculations, its size, cultivars, residue and energy production were same values as was used Kinnunen et al. (2016). The modelling of the biogas plant was done using Biokaasulaskuri[1], a calculator for the biogas plant investment. The assumed retention time of 30 days was used for the biogas reactor. The biogas production was calculated as a wet process, where dilution water was added if needed, to achieve total solids (TS) of 12% (1200 m^3 of dilution water used in the biowaste scenario). Biogas utilization was assumed to be utilized in combined heat and power (CHP) unit (conversion to 52% heat, 33% electricity). The operation of the biogas plant was assumed to use 15% of produced heat and 5% of produced electricity.

Nutrients in the digestate were calculated from the total concentrations in the vegetable residues. It can be assumed that around 50% of the total-N in the digestate is in its soluble form (NH4-N) which is the plant available form and is used when calculating the fertilization potential. The possible post-processing of the digestate nutrients was also analyzed with solid-liquid separation of the

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[1] http://portal.mtt.fi/portal/pls/portal/gas_mtt.gas_mtt_laskuri

digestate and ammonia stripping and scrubbing of the liquid fractions (Table 8). This treatment produces a mineral fertilizer-like ammonium nitrogen product for utilization in the greenhouse, while the solid part of the digestate could be used a phosphorus fertilizer.

5.2 Results and discussion

Scenario 1

The biogas production from the greenhouse's vegetable residues in Scenario 1 is possible in a small reactor size (under 7 m^3 with 3000 m^2 greenhouse, around 12 m^3 with 5000 m^2 greenhouse) as the total volume of the produced residue is relatively small. The reactor size can be even smaller, when dry-digestion use used. This can also have an effect on biogas plant energy use but in this calculation example, this option is excluded (due to small amount of references on dry-digestion energy consumption).

The production of energy from the residues from a 3000 m^2 greenhouse is 9.5 MWh/a as calculated from the produced heat and electricity from the CHP unit (Table 9). From the larger greenhouse (5000 m^2) residues produce almost double the energy amount, around 18 MWh/a. However, the total energy use of the 3000 m^2 greenhouse is as high as 5 GWh/a in BASE scenario and 3.4 GWh/a in the LED scenario. To this energy use, the biogas plant is able to contribute only 1% of the greenhouse's heat consumption and 0.14% of the electricity consumption. Overall, over 99% of the heat and electricity the greenhouse needs must be acquired outside the system (Table 9, Figure 6).

However, it has to be noted that the energy production figures used are rough averages from year around productions. In summer, the greenhouses with modern technology can even be energy producers (Jokinen 2015b). For example, from 20 to 50 MJ of electricity was used to produce one kilogram of fresh weight cucumber in mid-winter, while in summer the electricity consumption was from 5 to 25 MJ/kg (Kaukoranta et al. 2014). The average values used in this study was chosen, as the biomass is produced year-around, which means that the biogas production is more or less stable year around. In summer, also the energy consumption of the biogas plant decreases so the balancing with year-around energy production and consumption is difficult. One option is to store either the biomass or the produced energy (as gas) during the summer and increase the energy production in biogas plant in winter. Thus, in city-environment the storage option can also be expensive.

The most effective way to utilize the biogas is to utilize it as a gas by natural gas network and use other renewables (solar, wind), for energy production to greenhouse production. If the greenhouse is built to e.g. roof of industrial building, the extra heat from the building can be used for greenhouse heating. Different new technologies can also increase the energy efficiency in greenhouses (Kaukoranta et al 2014). In addition, in these calculations, effect of heat exchangers in biogas plant and/or heat produced by greenhouse in summer is not taken into account. The energy production of the biogas plant is also dependent on the characteristics of the vegetable residue, where different plants have different nutrient and methane potential characteristics. However, with co-digestion the total energy and nutrient amount produced in the biogas plant is increased, which was assessed in Scenario 2.

Nutrients produced from the digestate can be circulated back to the greenhouse's fertilization. In this example, the digestate P can supplement 52% of the P fertilization. Soluble-N and K contribute to fewer than 10% of the nutrient need of the greenhouse. In total, 50-90% of nutrients needs to be transported to the greenhouse as mineral fertilizers (Figure 6).

Table 9. The utilization of vegetable residues from a 3000 and 5000 m^2 greenhouse in a biogas plant and the potential of the produced heat, electricity and nutrients in the greenhouse (Scenario 1).

SCENARIO 1	**3000 m^2 greenhouse**			**5000 m^2 greenhouse**		
Energy (MWh/a)	***Heat***	***Electricity***		***Heat***	***Electricity***	
Energy consumption, BASE	900	4350		1500	7250	
Energy consumption, LED	600	2850		1000	4750	
Energy production in the biogas plant[a]	5.4	4.1		9.1	6.9	
Biogas potential, BASE (%)	1	0.09		1	0	
Biogas potential, LED (%)	1	0.14		1	0	
Nutrients (kg/a)	***Soluble-N***	***P***	***K***	***Soluble-N***	***P***	***K***
Nutrient need in greenhouse	1129	236	1672	1881	394	2787
Nutrient production in biogas plant	73	123	137	127	205	228
Digestate nutrient potential in greenhouse fertilization (%)	7	52	8	7	52	8

[a] The heat and electricity consumption of the biogas plant is subtracted, the concentration of nitrogen is not taken into consideration

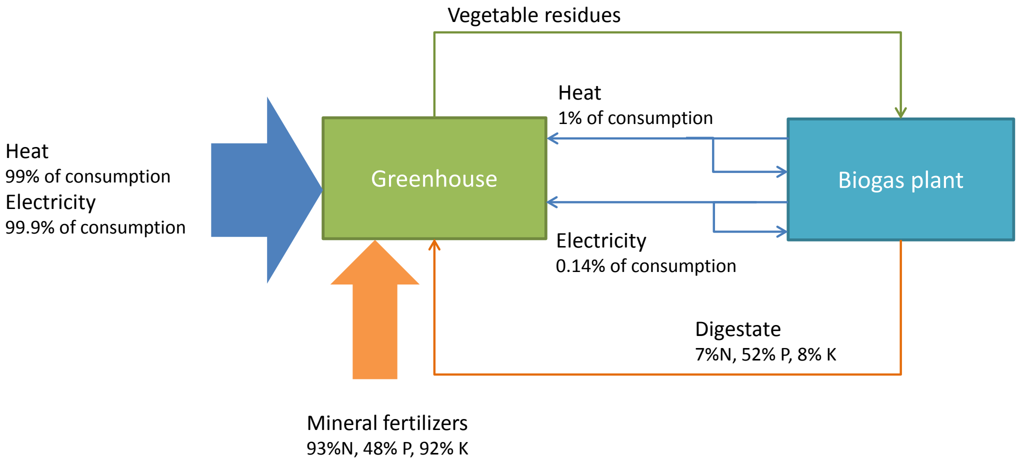

Figure 6. The energy and nutrient flows in Scenario 1/LED Scenario with 3000 m^2 greenhouse.

Scenario 2

In Scenario 2, the co-digestion of the vegetable residues from the greenhouse with municipal biowaste was studied. Biowaste is produced in high quantities and it contains nutrients from the wasted food. Wastewater sludge produced from the city area was excluded in this example, as according to present Finnish legislation, the nutrients from wastewater sludge cannot be used in greenhouse cultivation. Compared to Scenario 1, larger reactor size (around 200 m^3) and dilution water is needed if digestion is executed as a wet process, as the biowaste volume and solids content is high.

Adding of the biowaste increases the energy production of the biogas plant from around 10 to 330 MWh/a (3000 m^2 greenhouse, Tables 10 and 9). Furthermore, the heat produced in the CHP could account for over 50% of the heat consumption of the greenhouse in the LED scenario and 10% of electricity. The nutrients produced during the digestion of vegetable residues and biowaste can be recirculated back to the greenhouse to supplement 100% of the fertilizer need. Additionally, residual nutrients correspond to 40-350% of the greenhouse nutrient demand, which can be used e.g. in crop fertilization nearby the city. In total, due to the addition of the municipal biowaste to the digester as a co-feedstock, the nutrient and energy balance is improved and the nutrient need of the greenhouse can be fully fulfilled.

Additionally, the digestate can be further treated to produce more mineral fertilizer-like products for the greenhouse fertilization and to balance the N/P ratio of the fertilizer. The production of N fertilizer through digestate solid-liquid separation and ammonia stripping was calculated. The energy use of the treatment was in Scenario 2 (3000 m^2 greenhouse) 36 MWh of heat and 7 MWh of electricity, which will reduce the energy flow recycled back to the greenhouse from the biogas plant, thus increasing the usability of the digestate nutrients.

Table 10. The utilization of vegetable residues from a 3000 and 5000 m2 greenhouse and municipal biowaste in a biogas plant and the potential of the produced heat, electricity and nutrients in the greenhouse.

SCENARIO 2	**3000 m^2 greenhouse**			**5000 m^2 greenhouse**		
Energy (MWh/a)	***Heat***	***Electricity***		***Heat***	***Electricity***	
Energy consumption, BASE	900	4350		1500	7250	
Energy consumption, LED	600	2850		1000	4750	
Energy production in the biogas plant[a]	333.8	252.6		337.4	255.4	
Energy production in the biogas plant[b]	297.3	245.4		299.0	247.8	
Biogas potential, BASE (%)	37	6		22	4	
Biogas potential, LED (%)[a]	56	9		34	5	
Biogas potential, LED (%)[b]	50	9		30	5	
Nutrients (kg/a)	***Soluble-N***	***P***	***K***	***Soluble-N***	***P***	***K***
Nutrient need in greenhouse	1129	236	1672	1881	394	2787
Nutrient production in biogas plant	3088	1039	2353	3138	1121	2445
Digestate nutrient potential in greenhouse fertilization (%)	274	440	141	167	285	88

[a] The heat and electricity consumption of the biogas plant is subtracted, the concentration of nitrogen is not taken into consideration

[b] The heat and electricity consumption of the biogas plant is subtracted, the concentration of nitrogen with solid-liquid separation and ammonia stripping is taken into consideration

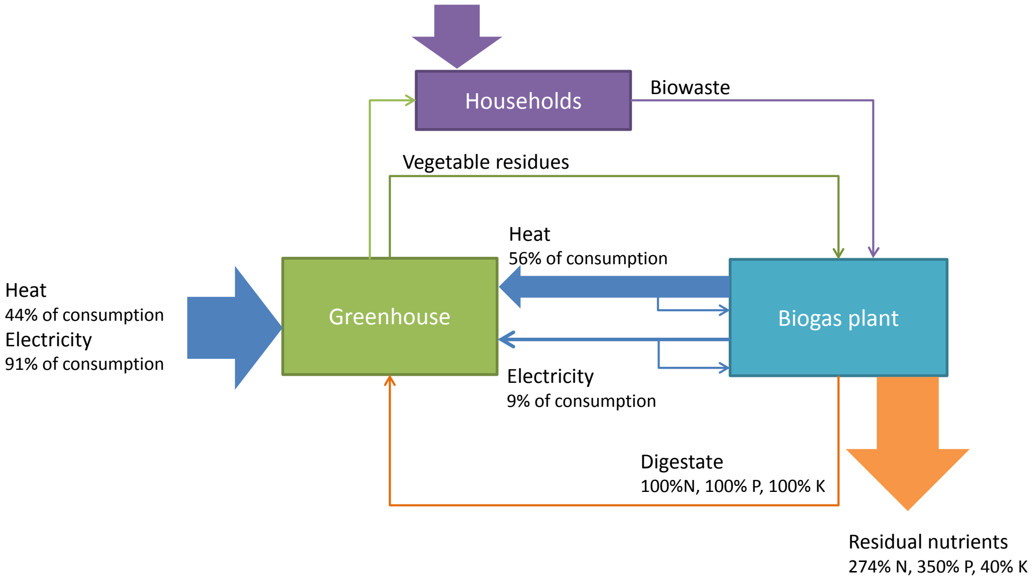

Figure 7. Greenhouse with household biowaste

6 Conclusions

City structures change slowly. In many cases, it is impossible to change systems to more efficient because of the historical value of buildings. Big practical obstacle or drag is often private land ownership. If owner is not willing to sell the land needed for example biorefinery plant, it will slow down the whole process. In many cases, building something new (greenhouse, power plant, e.g.) which is not usually built in city areas, will most probably raise a concern about noise and odor in people living in those areas. It means that people's participation comes more and more important.

In the best case, the symbiosis between different processes may bring advantages such as new and diversified markets, increasing revenue streams, and enhancing business resilience. With proper process conditions and good planning, the environmental benefits can also come through improvements in energy efficiency, successful capture and reuse of by-products, reduction of landfill waste and wastewater and improved use of agricultural land. New business opportunities for companies can be created by focusing on turning all by-products into valuable products.

Still, more research is needs for ensuring sustainable practices for future cities. E.g. following subjects need to be covered:

- Defined economic and environmental impacts of various scenarios
- Integration of appropriate agricultural/forestry biomasses into city energy systems
- Using biomass from various sources as energy storage
- Participation of residents into planning processes
- Prediction of changes on consumer and diet habits and how to possibly modify them
- Integration of different technologies e.g. in terms of efficient energy utilization and minimization of greenhouse gas emissions
- Construction of pilots e.g. urban greenhouses and biogas production plants
- Urban planning considering the diversified demands and even claims of the inhabitants
- Assessment of optimal city size; today cities are assumed to grow as a megacity but what will be the size of the city where destructive impacts are minimized but people's welfare is maximized?
- Adaptation requests for the transportation schemes in the upcoming cities while e.g. the way of working and social actions will diverge
- Utilization of system modeling and optimization approach for the planning processes of a city structure and function

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