THE GARDEN CITY

– a sustainable alternative – Report summary

A COMPARATIVE STUDY BETWEEN GARDEN CITIES AND DENSE URBAN AREAS DECEMBER 2021

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Content

Garden cities – a sustainable alternative!

Today's urban development strives for sustainable urban solutions. Two of the strongest drivers for this are rapid urbanization and climate change. In recent decades, dense, compact urban development has been seen as the environmentally sustainable ideal and leaves very little room for single-family houses. The main reasons why dense, compact urban area has been seen as the ideal are that it can accommodate more inhabitants within a limited area, and that it supports an efficient public transport system that reduces car use. Single-family houses have been associated with an assumption that they are not sustainable as they have a larger land use and encourage commuting to work with fossil fuel powered cars.

7 out of 10

Swedes want to live in a single-family or semi-detached house!

However, a survey from the National Board of Housing, Building and Planning shows that a majority of Swedes express an interest in living in single-family houses or semi-detached houses. Therefore, we have asked ourselves – Can this be achieved without compromising the climate and environmental sustainability? **That is, can garden cities with a majority of detached or semi-detached single-family houses be sustainable? The answer is yes!**

Purpose and focus

Based on a number of sustainability aspects, this study compares dense, compact urban development with an urban area designed as a modern garden city with a large proportion of single-family houses. The main focus of the study is the green-house gas emissions from the residential buildings at a neighborhood level. In addition, mobility patterns and the monetary value of the urban areas' ecosystem services have been analyzed.

The results from the study

At a neighborhood level, the dense, compact urban area's climate impact is as much as 150 percent larger than the garden city's climate impact. Calculated per capita, the dense, compact urban area's climate impact is 60 percent larger, or in other words worse, than the garden city's climate impact.

The economic valuation of the ecosystem services that has been carried out shows that the monetary value of the ecosystem services in the dense, compact urban area is only 70 percent of the monetary value of the ecosystem services in the garden city. Calculated per capita, the value of the ecosystem services is less than half in the dense, compact urban area compared to the garden city. Garden cities are thus in several aspects significantly more sustainable than dense, compact cities. A benefit of the compact urban area is that it can accommodate more people, but it is not necessarily more sustainable.

But neither the garden city nor the dense, compact urban area is the best solution from the perspective of all sustainability aspects, and a combination of areas of different character is needed to create the most sustainable urban environments. For this reason, we believe that more neighborhoods with a garden-city character must be integrated into urban development. Creating a mix between dense areas and more areas with a garden city character can contribute to increased sustainability, while at the same time accommodating the way many Swedes want to live. A larger selection of housing types can also contribute to increased diversity in a city.

One way to create more sustainable cities is to integrate more areas with a garden city character with single-family houses in the urban development, and thereby create a variation of dense, compact urban areas and garden cities.

What is sustainable urban development?

Sustainable development is often defined as a development that meets the needs of the present without compromising future generations' ability to meet their needs. In line with this, the goal of sustainable urban planning should be to create a resource-efficient, attractive and smart built environment, to meet the needs of the citizens and to create conditions for the citizens to lead a sustainable life.

Sustainable urban development must contribute to ecological as well as social and economic sustainability. The three aspects of sustainability are strongly related to each other, and all three must be included. This means that several different factors need to be considered at the same time – design, the disposition of green areas, the population density, a range of services and facilities, a variation of building types, transport infrastructure and mobility solutions, the provision of ecosystem services, etc. The design of all these aspects is crucial for the sustainability performance of a neighborhood. Hence, to create social, economic, and environmentally sustainable societies requires a multidisciplinary approach.

What is a garden city?

A garden city is something in between a densely built urban area with high-rise buildings (4 floors or more) and the pure single-family housing area. Garden cities are characterized by a medium-density population and a variety of housing types with single-family houses, semi-detached houses, low-rise apartment buildings etc. They are also characterized by small squares, with a varied range of services in or near the area, private gardens and streets lined with greenery. Ebenezer Howard, who invented the term garden city, describes its characteristics as *"A combination of the advantages of the most energetic and active town life, with all the beauty and delight of the country".*

The garden city is mainly characterized by a medium-density population, a varied selection of housing types, access to a varied selection of services, private gardens, and streets lined with greenery.

A comparative analysis of a garden city and a dense, compact urban area development

The work is based on a scenario analysis, and the following sustainability aspects have been analyzed:

- **Climate impact:** A life cycle assessment (LCA) has been carried out for residential buildings, streets and parking lots. These factors have a high climate impact, and it is these factors that are considered to differ most between the scenarios.
- **The value of the ecosystem services:** Monetary evaluation of the ecosystem services.
- **Travel, mobility and social aspects.**

To enable the comparison, scenarios for a garden city and a dense, compact urban area have been designed. They have been assumed to be built on an area of 64 hectares in a neighboring municipality to Stockholm. In the analyses, the two scenarios have been designed with exactly the same area and a green area factor (GAF) which in both cases is approximately 0.5. Both of the scenarios are considered to provide sufficient services for their respective number of inhabitants.

(1) The Brundtland commission, definition sustainable development https://fn.se/wp-content/uploads/2016/08/Faktablad-2-12-H%C3%A5llbar-utveckling.pdf

Description of the two compared scenarios

The garden city

The garden city scenario has a mixture of detached and semi-detached houses, and four floor apartment buildings. The garden city has been designed to enable 70 percent of the inhabitants to live in single-family houses. This is to correspond to the interest expressed in the National Board of Housing, Building and Planning's survey on how people in Sweden want to live.

The table to the right summarizes the design parameters that have been used for the garden city. As can be seen from the table, the population density is 59 persons per hectare, and the per capita the private green areas are almost twice as large as the public green areas.

Attribute	Value
Number of buildings	476
Number of apartments	1 280
Inhabitants	3 806
Population density	59 pers/ha
Public green space	32 m²/capita
Private and semi-private green space	61 m²/capita

The dense, compact urban area

The scenario for the dense, compact area consists of a number of identical apartment buildings in concrete with 4-6 floors. The inspiration for these buildings comes from the houses that have been analyzed from a life cycle perspective and published in a report by the Swedish Environmental Research Institute, IVL (Minskad klimatpåverkan från nybyggda flerbostadshus (2018), available in Swedish only).[3]

The table to the right shows the design parameters that have been used for the dense, compact urban area. As shown in the table, the population density in this scenario is 92 people per hectare, and the per capita private green areas make up less than a quarter of the public green areas per capita.

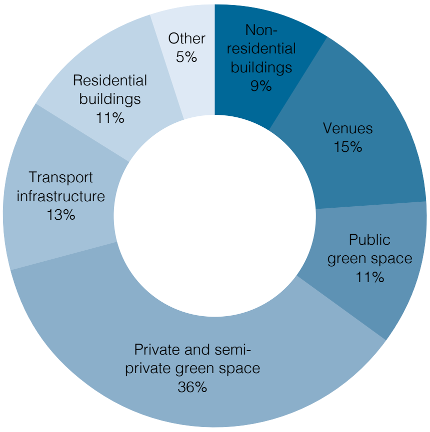
Attribute	Value
Number of buildings	72
Number of apartments	1 746
Inhabitants	5 940
Population density	92 pers/ha
Public green space	47 m²/capita
Private and semi-private green space	11 m²/capita

What differentiates the two scenarios?

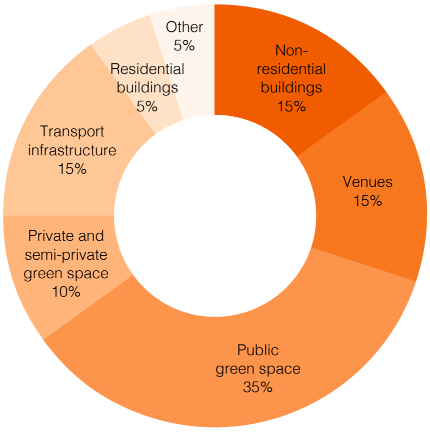
An important difference is that the dense, compact urban area can accommodate more people than the garden city. Population density is one of the main reasons for the general, but incorrect, assumption that dense urban areas are more sustainable than garden cities, which has dominated the discussion in recent decades.

In the analyses made, the population density is 60 percent higher in the dense, compact urban area compared to the garden city. The pie charts present the proportion of land used for different purposes in the scenarios for the different types of areas. The diagrams show that the residential buildings occupy twice as much land in the garden city as in the dense, compact urban area. It is also worth noting that there is an inverse relationship between the proportion of public green spaces and private or semi-private green spaces, where the latter dominate in the garden city.

LAND USE
GARDEN CITY



LAND USE
DENSE, COMPACT URBAN AREA



Comparison of the climate impact between the garden city and the dense, compact city

The diagrams on the next page show the estimated climate impact from residential buildings, streets and parking lots in the garden city and the dense, compact urban area. *The results are shown both in total emissions for the area and in emissions per capita.* The estimated CO_2 equivalent emissions for the residential buildings and the parking spaces are significantly lower in the garden city than in the dense, compact urban area. This applies both to the urban area as a whole and per capita. In terms of road infrastructure, i.e. the construction of the roads, the garden city's carbon dioxide emissions per capita are slightly higher than in the dense, compact urban area. But at area level the road infrastructure has a lower climate impact in the garden city than in the dense, compact urban area.

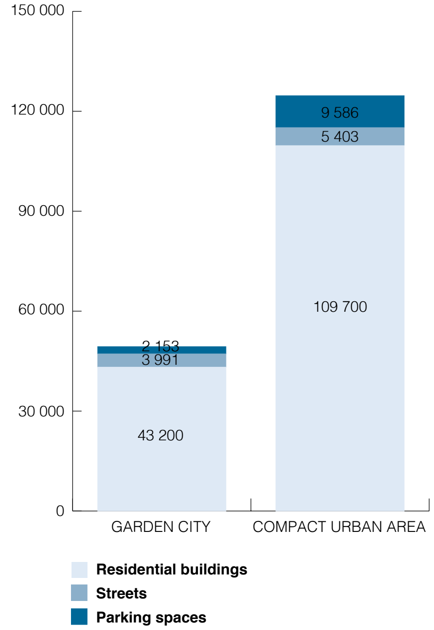
At area level:

The climate impact of the garden city is less than half the impact of the dense, compact urban area.

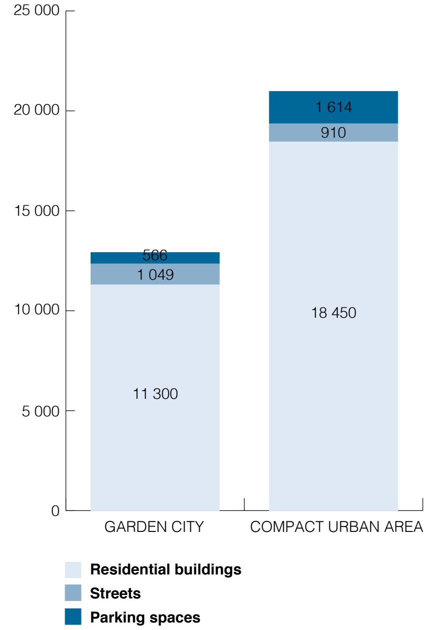
Per capita:

The climate impact from the garden city is only 60 per cent of the dense, compact urban area's climate impact.

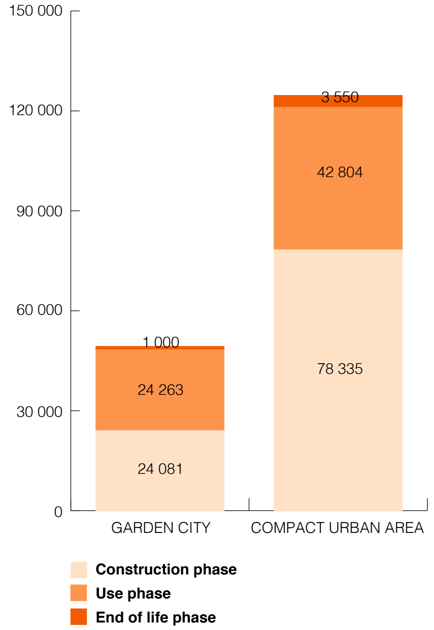
CLIMATE IMPACT AT AREA LEVEL (TON CO_2e)



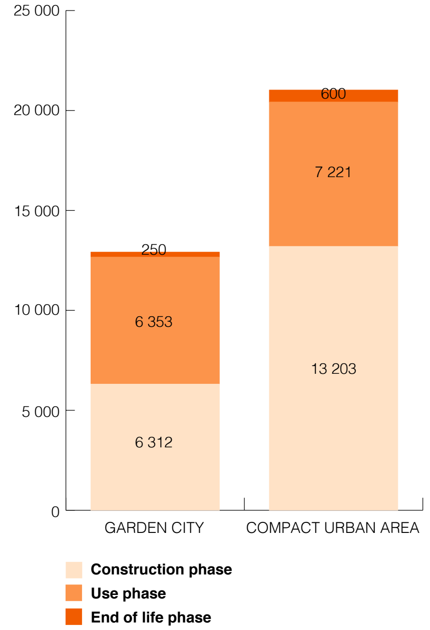
CLIMATE IMPACT PER CAPITA (kg CO_2e/capita)



CLIMATE IMPACT AT AREA LEVEL, DISTRIBUTED OVER LIFE CYCLE PHASES (TON CO_2e)



CLIMATE IMPACT PER CAPITA DISTRIBUTED OVER LIFE CYCLE PHASES (kg CO_2e/capita)



The two top diagrams show the climate impact distributed over the entire life cycle for the two urban area scenarios, while the two lower diagrams show the scenarios' climate impact divided between the construction phase, the use phase and the end-of-life phase. The results are shown both in total emissions at urban area level and in emissions per capita. As shown in the diagrams, the buildings' construction phase CO_{2e} emissions are significantly lower in the garden city than in the dense, compact urban area. During the use phase, the climate impact per capita is relatively similar between the two urban area types.

Results from the analysis show that the construction phase can cause as great a climate impact as the use phase. Hence, it's necessary to analyze the climate impact based on the entire life cycle.

Are the garden cities not dependent on cars? How can that be sustainable?

There is no clear connection between building type and car ownership, but car ownership per capita is generally greater in areas with single-family houses than in denser urban areas. One reason for this is that families with children are more common in single-family housing areas, while single-person households are more common in dense, compact urban areas.

An important question is whether a garden city can have an efficient public transport system. The answer is yes, it can. Statistics from the Swedish Associations of Local Authorities and Regions (SKR, 2016) show that a residential area with more than 50 inhabitants per hectare can support an efficient public transport system. With the building structure assumed in our analysis, the garden city has a population density of 59 people per hectare. This means that the population density is high enough to provide a basis for a well-functioning public transport system, and the garden city's residents will not depend on having access to their own car.

Another important issue is the negative climate effects of car ownership. The more cars there are in a neighborhood, the more roads, parking spaces and other transport infrastructure is required to avoid congestion and to accommodate the cars.

A larger car dependency leads to higher fuel consumption. However, as the car fleet becomes increasingly electrified, the cars' climate impact decreases. The car fleet is expected to become carbon neutral within a couple of decades, which is why this objection to a major extent can be considered taken care of. In 2021, electric vehicles accounted for almost half of all new car sales in Sweden. During the future garden city's operational phase, it can even be more climate smart to use electric cars than, for example, buses, if the average public transport occupancy is low.

As the vehicle fleet is electrified, the car's climate impact will decrease. Tomorrow's car fleet is expected to be carbon neutral within a couple of decades, and therefore its climate impact can largely be considered irrelevant. In 2021, rechargeable cars accounted for almost half of all new car sales in Sweden. During the garden city's lifespan, it can be more climate smart to use electric cars than buses for example, if the average occupancy of public transport is not sufficiently high.

50 inhabitants/ha is a sufficient density for an efficient public transport system.

Electric cars can be a more sustainable solution than public transport if the public transport occupancy is low.

Foto: Shutterstock

Foto: Shutterstock

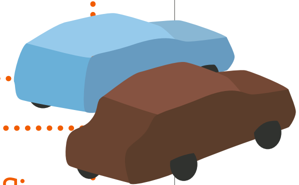
There are more cars in the dense, compact urban area

There are more cars in the dense, compact urban area than in the garden city. But the car ownership per capita is greater in the garden city than in the dense, compact urban area. Our analysis shows that a mixture of socio-economic factors and access to services and parking spaces are the characteristics that mainly affect car ownership as well as the distances driven. Several scientific studies have shown that there is a connection between parking supply and car ownership, and between the supply of parking spaces and the number of trips made. One explanation to the fact that there is a larger share of car ownership in single-family house areas may be that it is easier for those who live there to park the car compared to the in dense, compact urban areas.

But as mentioned earlier, socio-economic factors such as education, occupation, income, family situation, etc. also have a direct decisive effect on car ownership, since these factors significantly affect travel and mobility patterns. A large proportion of the population in Sweden has access to a car. An analysis of the correlation between car ownership and family situation shows that families with children in single-family houses is the group with the highest car ownership (96 percent). An analysis of the correlation between car ownership and income shows that car ownership increases with increased income.

A mix of features is one of the most important factors in creating a sustainable urban area. Our analysis has not shown any connection between building type and access to public spaces. But compact urban areas can often offer a wider range of public and commercial services than the garden cities, which may mean a wider range of service providers to choose between.

Parking supply affects: Easier access to parking spaces can explain a larger car ownership in garden cities than in dense, compact urban areas.



Socio economic aspects affect car ownership and travelling: A large proportion of families with children live in the garden city, and they have a larger access to cars than others.

A functional mix and access to urban qualities and services: There is no clear relationship between building type/ population density and access to public spaces.

Ecosystem services and their value

Why are ecosystems important?

Plants and small organisms purify both air and water from toxins and pollutants, bumblebees and bees pollinate trees and shrubs, so that we get berries and fruit, and humans' feel peace by visiting green spaces, such as a park or a forest. All of these are different examples of ecosystem services that contribute to our welfare and quality of life. They make up the green infrastructure in urban areas and are just as important to our communities as our buildings and infrastructure are. The ecosystem services can be summarized as all the benefits provided by nature to humans for free.

How do you value ecosystem services?

Because the benefits of ecosystem services are for free, we often take them for granted and forget to value their contribution to our well-being. Hence, models and tools are needed to make the value of ecosystem services visible. One way is to value the services in monetary terms. In this study, only a selection of all the ecosystem services have been evaluated. The total value of ecosystem services is estimated based on the benefits that trees, shrubs and grass generate, and the significance of these benefits for humans. Examples of benefits are the purification of air pollutants, what people are willing to pay for access to a garden, and the avoided societal cost thanks to plants absorbing and purifying water.

The illustration below shows the ecosystem services that have been analyzed in this study. Ecosys-tem services contribute to economic, social and environmental sustainability.

MONETARY VALUED ECOSYSTEM SERVICES

QUALITATIVELY DESCRIBED ECOSYSTEM SERVICES

The value of ecosystem services

The monetary value has been calculated for the ecosystem services that are marked in blue in the illustration on the previous page for the garden city and the dense, compact urban area scenarios. It is important to point out that the valuation is not comprehensive, but illustrates a part of the total value generated by the ecosystem services. The reason why only a part of the value of the ecosystem services has been calculated is because a monetary valuation is very uncertain for most of the ecosystem services, but it is still a way of highlighting the various benefits they provide. The results from the analysis should therefore be interpreted as an indication of the total value of the ecosystem services, **where the true value is most likely significantly higher.**

Why evaluate ecosystem services?

These types of comparisons create economic incentives to promote more green space in urban environments, which generate ecosystem services that contribute to improved quality of life and welfare.

By evaluating ecosystem services in connection with urban planning, the ecological aspects can be included in decision-making in a completely different way. It makes it possible to consider more aspects in urban planning and development, and how these aspects interact with each other in sustainable urban development.

Ecosystem services are crucial for creating resilient urban environments that are planned and developed in interaction with nature.

Foto: Shutterstock

Gardens provide opportunities for food cultivation that creates well-being and not least generates healthy food that reduces household expenses.

Foto: Shutterstock

Bees and bumblebees are the most important pollinators. Thanks to them we get, fruits, berries and beautiful greenery.

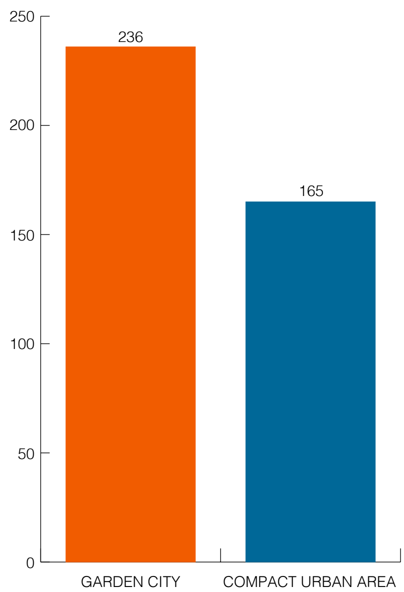
Foto: Shutterstock

The value of ecosystem services is more than twice as high in the garden city

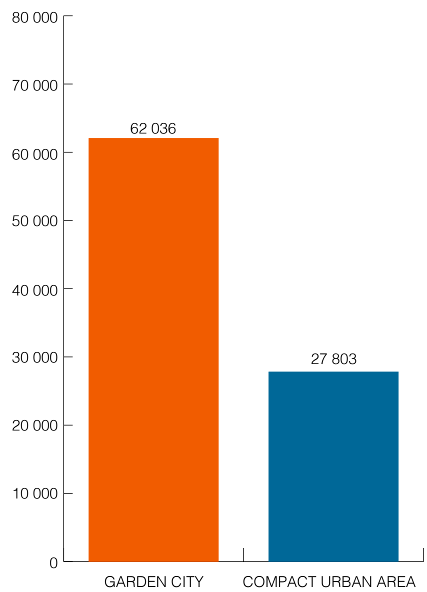
The diagrams show the estimated value of the ecosystem services air purification, noise regulation, water purification and regulation, food supply, social interaction, mental well-being and physical health. The value is calculated both for each neighborhood and per capita. A summary of the results shows that the value of the ecosystem services in the garden city is more than 40 percent higher at an area level, and more than twice as high per capita compared to the dense, compact urban area.

> Calculated per capita, the value of ecosystem services is more than twice as high in the garden city than in the dense, compact urban area.

TOTAL VALUE FOR THE AREA (MSEK)



VALUE PER CAPITA (SEK/YEAR)



The reason why the value of ecosystem services is higher in the garden city is mainly because:

- There are more trees in the garden city
- It has gardens that create social and health benefits
- It has proximity to green areas and the green area per person is larger

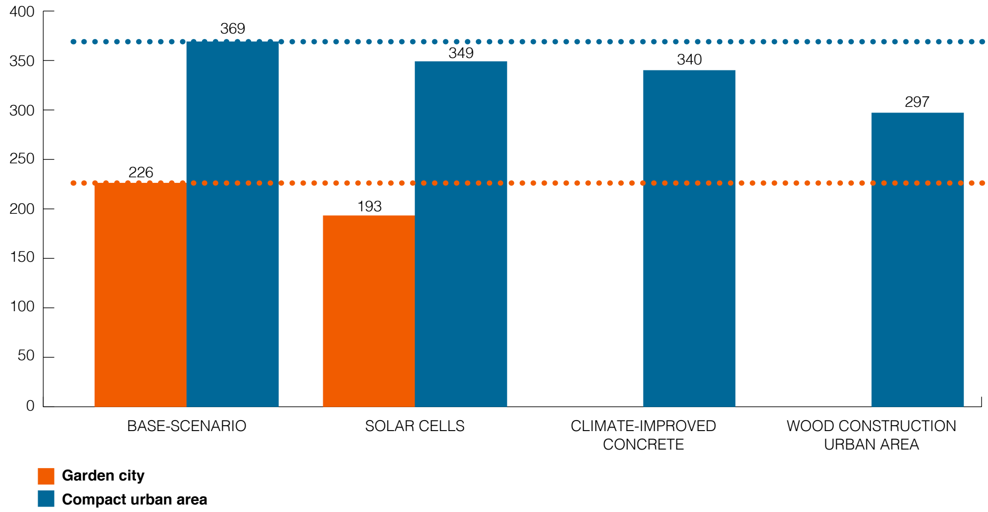
Assumptions regarding the scenarios' residential buildings

The previously described two scenarios are largely simplified with regards to assumptions about how the residential buildings are designed. For both the garden city and the dense, compact urban area, a base scenario has been used in the climate impact analyses. For the garden city it has been assumed that all single-family houses have a wooden construction (already today, 90 percent of all Swedish single-family houses are of wooden construction) and for the dense, compact urban area it has been assumed that all the apartment buildings are of mainly concrete construction. In a sensitivity analysis of the areas' climate impact, other materials in the dense, compact urban area's building structure have therefore been analyzed. Furthermore, the climate impact of installing solar cells (photo voltaic) on the roofs in both the urban area scenarios has been analyzed. The diagrams below present the climate impact per capita from the residential buildings compared with the base scenario.

The changes that have been made in the residential buildings in the sensitivity analysis are:

- Installation of solar cells (PV) on 50 percent of the roofs in both the garden city and the dense, compact urban area
- Choosing low-carbon concrete for the buildings in the dense, compact urban area
- Choosing wood instead of concrete for the residential buildings in the dense, compact urban area

CLIMATE IMPACT FROM RESIDENTIAL BUILDINGS PER CAPITA PER AREA FOR EACH ASSUMPTION (KG CO_2e/CAPITA, YEAR)



The diagram shows that the installation of solar cells would lead to a reduction of the climate impact by 5 percent for the dense, compact urban area, and 17 percent for the garden city respectively. Choosing low-carbon concrete would decrease the dense, compact urban area's CO_2 equivalent emissions per capita and by 8 percent, while changing the residential building construction material from concrete to wood in the dense, compact urban area would reduce the CO2 emissions per capita by 20 percent.

In summary:

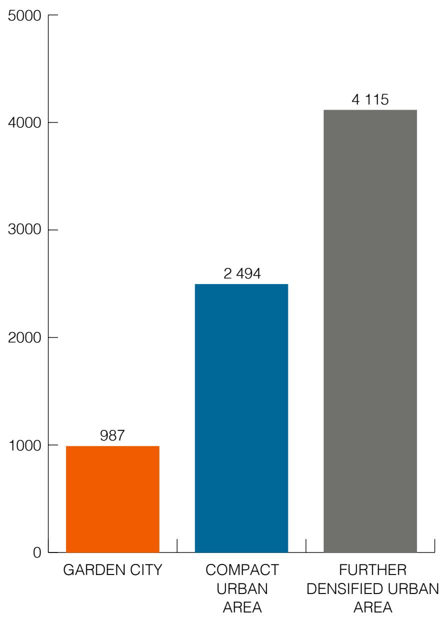
Regardless of material choice – the garden city has a lower climate impact than the dense, compact urban area.

Assumptions in the urban areas

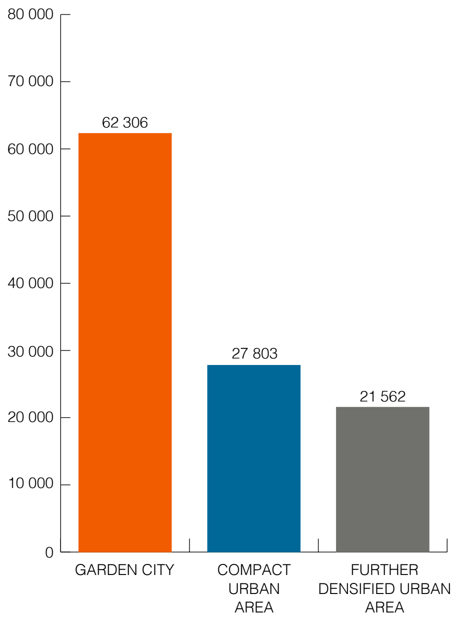
A second sensitivity analysis that has been carried out is to assess the significance of a further densification of the buildings in the dense, compact urban area scenario. The additional buildings have been assumed to be of the same type as in the base scenario for the dense, compact urban area (concrete construction multi-family houses). The population in the further densified urban area is 9,900, compared to 5,940 in the dense compact urban area, and 3,806 in the garden city. The green area factor (GAF) in the further densified urban area is still 0.5, which is made possible by partially replacing the green areas on the ground with green roofs.

The result of this analysis is that the climate impact per capita is at the same level as in the base scenario for the dense, compact urban area since the number of buildings has increased in proportion to the increased number of inhabitants. However, as a result from the further densified scenario accommodating more buildings spread over the same area, the further densified urban area scenario has a 1.7 times higher climate impact from the residential buildings than the dense, compact urban area's base scenario. Furthermore, the value of the ecosystem services per capita is decreased in the further densified urban area compared with the two base scenarios. The value of the ecosystem services decreases by one-fifth compared to the base scenario of the dense, compact urban area, and is a third of the value of the ecosystem services in the garden city. The main reason for the significantly reduced value for ecosystem services in the further densified urban area is that a large part of the green space has been moved from the ground to the roofs, and this does not provide the same conditions for ecosystem services.

CLIMATE IMPACT AT AREA LEVEL (TON CO_2e/YEAR)



THE VALUE OF ECOSYSTEM SERVICES PER CAPITA (SEK, YEAR)



The further densified urban area generates:

70 percent higher CO_2 emissions and 22 percent lower ecosystem services value per capita than the compact urban area.

Concluding reflections

The compact urban development model has long been considered the ideal design that creates environmentally sustainable cities. Our study shows that garden cities in many respects are significantly more sustainable than compact urban areas.

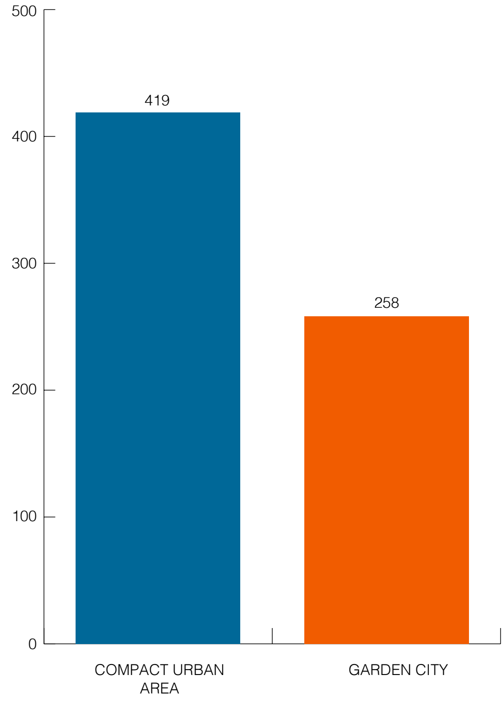
Garden cities provide:

- Lower climate impact from residential buildings and transport infrastructure, on an area level as well as per capita
- Higher monetary value of ecosystem services, on an area level as well as per capita
- Corresponds to the majority's preferred choice of living
- Increased social sustainability through increased security and a sense of belonging

As a consequence of this, we have to change the way we plan and build our cities and communities. We need to provide garden cities with more space, as they contribute to increased sustainability while at the same time enable the type of life that most people prefer.

An increased integration of neighborhoods with a garden city character in the urban development is a viable solution in society's pursuit for sustainable urban solutions. A variation between dense urban areas and garden cities also provides a wider selection of types of homes, and thus creates greater diversity in the city.

CLIMATE IMPACT PER CAPITA PER AREA (KG CO_2e/YEAR)



ECOSYSTEM SERVICES – VALUE PER CAPITA

COMPACT URBAN AREA
27 803 SEK/YEAR

GARDEN CITY
62 036 SEK/YEAR

Appendix

Methodology

Urban planning

The basis for the two scenarios that have been designed is an undeveloped area of 64.4 ha in Sundbyberg, a neighboring municipality to Stockholm. Both scenarios include sufficient services for their respective number of inhabitants (based on indicators from the Sweden Green Building Council's sustainability certification scheme Citylab), as well as a well-designed transport infrastructure. Furthermore, they have a green area factor (GAF) of at least 0.5, which is a common municipal requirement to ensure adequate ecosystem services in the development of new urban areas.

The residential buildings in the garden city consist of 1.5 storey detached houses of 150 m^2, two-storey detached houses of 175 m^2, semi-detached houses of 120 m^2 and 4-storey wooden multi-family buildings of 1,636 m^2 (a total of 476 buildings), In the dense, compact urban area scenario, the residential buildings consist of 18 blocks each with 4 multi-family buildings of 4-6 floors. Car parking spaces in the dense, compact urban area are provided through underground garages, while in the garden city carports or open-air parking is used for parking.

Sustainability evaluation

The Sweden Green Building Council's sustainability certification system CityLab for urban area development has been used as a framework for the aspects that have been evaluated in this sustainability comparison.[6] CityLab for districts has also been used to set the minimum requirements for land distribution between different services and functions.

Life cycle assessment (LCA) has been used for the study's focus area of this study, which is *the residential building sector's greenhouse gas emissions*. LCA has also been used for analyzing the *CO_2 emissions of the car parking spaces*.

For the *road infrastructure* a study from VTI (Swedish National Road and Transport Research Institute) (Karlsson & Carlson, 2010) has been used to calculate the CO2 emissions for construction, operation and maintenance of streets and roads. The traffic infrastructure and traffic flow scenarios have been based on a selection of existing areas in the Stockholm region that have been used as references.

Traffic-related behavior (mobility) has mainly been analyzed based on literature review and an analysis of the selection of reference areas mentioned above.

Social aspects have been evaluated qualitatively based on surveys and theoretical data.

Ecosystem services have been evaluated quantitatively by a socio-economic analysis where possible. For other ecosystem services, merely a qualitative assessment has been made. Values have been compiled based on literature review and in dialogue with researchers at the Swedish University of Agricultural Sciences (SLU). Only values that can be used for value transfer for the various green elements have been included in the assessment.

Calculations per unit area of residential buildings in the scenario have also been made for the evaluation of ecosystem services and the residential buildings' climate impact.

LCA for residential buildings

The compact urban area's buildings are equal to the buildings that are analyzed and reported in "Reduced climate impact from newly built apartment buildings" (Malmqvist, T. et al, 2018). (Minskad klimatpåverkan från nybyggda flerbostadshus, Malmqvist, T. et al, 2018, available in Swedish only). For the other residential building types, LCA analyses have been carried out in the same way as Malmqvist's analysis. All of the analyses are based on a lifespan of 50 years. The BECE software (Basic Energy and CO_2 Emis-

(6) CityLab for urban area development, Sweden Green Building Council (SGBC), https://www.sgbc.se/app/uploads/2019/04/Remissversion-Citylab-certifiering-av-stadsdelar.pdf

sions for Buildings) (Wallhagen, M. et al, 2011) has been used for the calculations of LCA stage A1-3. For the remaining phases, calculations have been made based on data from the individual house manufacturers, information from the literature review, and estimates based on data from the buildings that were analyzed in “Reduced climate impact from newly built apartment buildings” (Malmqvist et al, 2018).

Alternatives

Solar cells

Silicon solar cells were installed on 50 percent of the roofs in both the garden city and the dense, compact urban area.

Low-carbon concrete

The concrete used in all residential buildings in the compact urban area was replaced with low-carbon concrete, where a part of the portland cement was replaced by fly ash and slag.

Wood constructions in the compact urban area

All concrete construction residential buildings in the compact urban area scenario were replaced with wooden buildings. The LCA results (kg CO_{2e}/m^2A_{temp}) from the study “Reduced climate impact from newly built apartment buildings” (Minskad klimatpåverkan från nybyggda flerbostadshus, Malmqvist, T. et al, 2018, available in Swedish only) were used unaltered.

Assumptions

Heating

Single-family houses and semi-detached houses in the garden city scenario are assumed to be heated with a heat pump. The multi-family buildings in the garden city scenario are assumed to use geothermal heat pumps and solar photo voltaic systems. The multi-family buildings in the compact urban area scenario have been assumed to be heated by district heating. The Nordic electricity mix has been assumed to be used for all buildings.

Solceller

Poly-Si solar panels with a climate footprint of 20 g CO_{2e}/kWh generated electricity have been assumed (Swedish Solar Energy, 2018). For the comparison, the Nordic electricity mix (2016) with an emission factor of 102g CO_{2e}/kWh has been used. The solar cells are assumed to provide 80 percent of the energy use excluding household electricity and have a lifespan of 50 years.

Transport infrastructure

The transport infrastructure has been assumed to consist of materials with the same CO2 emissions in both of the scenarios, but the ratio between main streets and local streets varies based on the selected reference areas. For the garden city it has been assumed that car ownership is one car per household, while for the dense, compact urban area, it has been assumed that there are 0.5 passenger cars per household. Assumptions regarding land use for transport infrastructure are based on Tegelberg & Svensson’s (Tegelberg & Svensson, 2013) values. This means that 13 percent of the land in the garden city and 15 percent of the land in the compact urban area are assumed to be used for transport infrastructure.

Ecosystem services

Standard values from literature based on studies from sites have been used that differ in part from the specific reference areas described in this report, as the scenarios are only hypothetical. The values that have been presented are calculated with the help of, for example, the price database for socio-economic standard values from the Swedish Environmental Protection Agency and proxy values from empirical research.

Green area factor

The Green area factor (GAF) has in this study simplified been assumed to be the ratio between green areas and the scenarios’ entire area.

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FAQ

What would happen with CO_2 emissions if the multi-family buildings in the compact urban area were replaced by wooden buildings?

Answer: The climate impact of an average wooden multi-family building is approximately 20 percent lower than the climate impact of a corresponding house in concrete. But the garden city has an overall significantly lower climate impact than the dense, compact urban area regardless of the material choices of the multi-family buildings.

Why is the climate impact only to a limited extent is affected if the multi-family buildings would be made from wooden instead of concrete?

Answer: The dense, compact urban area requires more infrastructure, underground parking spaces have a larger climate impact, and measures for fire safety in tall buildings have a high climate impact (which doesn't have as great an impact in single-family houses).

How are the results of the analysis affected by the ongoing electrification of cars and road transport?

Answer: The car fleet in this analysis is not based on electric vehicles. Hence the electrification of the car fleet will likely further reduce the climate impact for garden cities. In the long term, the electrification of the transport sector could lead to car traffic having less impact in city planning.

The number of new single-family houses has been very low in Sweden for a long time, partly due to an urban development ideal based on densification. As a consequence, many municipalities have prioritized dense urban areas with multi-family buildings. This has mainly been motivated by a desire to reduce CO_2 emissions through reduced car use. Is this an important aspect to consider also in the future?

Answer: This is likely to be a less relevant issue. When the car fleet is fully electrified and the electricity supply is based on renewable energy sources, driving will in principle be CO_2 free. The arguments in favor of densification will then become less relevant, although other environmental aspects of car use remain. The car fleet is expected to be fully electrified in the near future.

Should municipalities be more restrictive in land-use, and not build on valuable agricultural land?

Answer: Yes, but the number of new single-family houses per capita is lower in Sweden than in almost any other European country, and this has been the case for a long time. Sweden also has more land per capita than almost all other European countries. The built environment only covers 3 percent of Sweden's area, and residential buildings cover only 1 percent. The rest of the built environment consists of offices, schools and other types of non-residential buildings, roads and other infrastructure, golf courses, other industries, ski resorts, etc. Furthermore, single-family houses could be built on more hilly, uneven terrain than forest and agricultural land.

Does the garden city have other advantages in terms of ecological sustainability?

Answer: Research shows that green areas have a positive effect on human well-being and health. Green vegetation contributes, among other things, to better regulated temperatures, cleaner air, recreational opportunities and to biodiversity. A holistic perspective is a prerequisite in sustainable urban planning. A variation of blue and green areas creating a network across the city is a necessity for biodiversity in urban environments. Garden cities are better suited to provide this than dense, compact urban areas.

Is a single-family house an economically sustainable form of living?

Answer: From the households' perspective, there are several factors that affect why owning a single-family home is an economically sustainable alternative. Long-term housing costs are often lower for a privately owned home compared to renting. This is because a real estate company needs to cover capital costs, including a return on equity. Single-family homeowners can often reduce their mortgage over time by amortization and as a result of inflation. Any increase in value of a single-family house also goes to the homeowner. In addition, many homeowners can do a lot of the maintenance themselves, which a tenant often must pay for.

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