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The relevancy of Masdar City for low carbon urban development in Norway

Irmelin Aamodt Moxnes
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Abstract

Masdar City has gained much attention for its carbon neutral and zero waste image. The thesis suggests that the carbon neutrality concept should be reconsidered as a worldwide development goal. Other more realistic and direct concepts, as low carbon development, should be used instead.

The thesis studies the relevancy of Masdar City for low carbon urban development in Norway. This is conducted by studying the city planning and metabolism measures. Original goals are compared with currently developed parts of Masdar City. Evidence is collected by literature reviews, observations and analyses. The gathered information is used to evaluate the city´s relevancy to Norway.

The results show that the measures made within urban form and building design in Masdar City are of relevance, but that the overall concept of Masdar City is of limited relevancy for low carbon urban development in Norway. One of the reasons is that the development has not fulfilled its original goals. However, it is also due to the already well developed recycling policy and renewable share in Norway.

The city can nevertheless still claim to be carbon neutral due to the limitations embedded in the overall concept. Carbon neutrality is currently set as a goal for Norwegian development as well. It is suggested that the goal is reconsidered and changed to a goal that does not disunite responsibility. Recommendation for further research is therefore to study how the current belief of carbon neutrality as a credible goal can be reconsidered in a worldwide context.

Foreword

This thesis is written at the Institute for Industrial Economics, Risk Management and Planning at the University of Stavanger in Norway.

I would like to give my supervisor, Daniela Müller-Eie, a special thanks. Her knowledge and guidance got me on the right track when I several times was headed in the wrong direction.

Further, I would like to thank my father, who traveled all the way to Masdar City with me. Without him this thesis would not have been realized.

I would also like to thank my mother and father for reading and commenting my work before delivery, and all my classmates and friends for their support and inspirational words.

Irmelin Aamodt Moxnes

Stavanger, 15th of June 2015

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1. Introduction

1.1 Background

Cities are responsible for more than 70 % of global carbon emissions (Reyes, 2013), which means that there is a great potential for improvement. If reduction is managed, there will be a greater chance of reducing climate change due to emission of carbon dioxide (WRI, C40Cities, & ICLEI, 2014). This will again positively affect the resources that cities depend upon, and highlights the importance of building more sustainably.

In 2014 54 % of the world's population lived in cities, and within 2050 it is assumed that 66 % will be living in cities (United Nations, 2014). Increased urbanization means that new cities have to be built and existing cities have to expand. At the same time this will lead to an increasing energy demand, and increased emissions, if measures are not taken. Usage of renewable energy sources will therefore be necessary to meet future energy demands, and preserve the environment.

Masdar City claims to be the first carbon neutral and zero waste city in the world. The city was planned by Foster + Partners in 2006 and is currently being built (Foster + Partners, 2007). It is located in Abu Dhabi, in the United Arab Emirates, and is planned to be finished in 2025/2030. A lot of new technology has been used, especially within renewable energy. At the same time the city aims to recycle 100 % of its waste. All the plans in Masdar are supposed to be adjusted to the cultural and climatic conditions. The principles are however, according to Foster + Partners (2007), possible to apply in the whole world. Would the principles used in Masdar City be relevant for urban development in Norway?

Despite very different climatic conditions, Norway and the United Arab Emirates do have similarities. Oil dependency is one of them. In addition, the countries greatest contrast; the hot/cold climate, are both sources for high dependency to electricity for heating and cooling. It may therefore be likely that the countries can use some of the same solutions in terms of low carbon planning.

> *"Urbanization has lured more people to bustling metropolises, but precious little thought has been given to what happens when these cities fail. Over time, the underlying systems and processes of civilization – from lead mining to offshore drilling to car commuting – slowly poison us. Power grids brown out, the climate heats up, and industrial accidents ravage ecosystems and cities alike. For all the famed cities with thousands of years of continuity – Paris, London, Cairo, Athens, Rome, Istanbul – most cities just stop."*
>
> *Ben Paynter, journalist*

Researching the city´s achievements before awarding Masdar City for being an answer to future sustainable urban planning is important. Like the statement implies, many cities stop functioning after some time, and it is hard to know their worth before investigating the city´s successes. By researching Masdar City´s relevancy to Norway the city´s credibility as a worldwide image will be put in question.

1.2 Problem

On the basis of the explanation in the background chapter, the main question in this master thesis becomes as follows:

Are the measures made in Masdar City relevant for low carbon urban development in Norway?

The thesis will study the original plans for Masdar City, and investigate what has been developed as of spring 2015 to become carbon neutral and zero waste. Further the thesis will discuss if and how the implemented solutions are relevant to Norway. The thesis aims to gather knowledge for those working with city planning in Norway, and to promote a more sustainable and low carbon city development.

To answer the research problem some additional questions are created:

1. What measures are planned to reduce carbon emissions in Masdar City?
2. Are the measures fulfilled and working as intended?
3. Are the measures relevant to Norway?

1.3 Delimitation and focal areas – the scope of the thesis

Kennedy and Sgouridis (2011) define a framework for carbon accounting in cities and their work is used to define the scope of this thesis. Their article intends to create common ground for people working to reduce carbon emission in cities. To do so they have divided the emissions from a city into different scopes. Their definition made it easier to delimit the focus area and also made the need for limitation clear.

According to Kennedy and Sgouridis (2011) a city is a system that is both very complex and dynamic. Defining its boarders and which carbon emissions that should be included can therefore be difficult. A city´s emissions cannot be connected only to the geographic boundary. Exchange of important goods that the city depends on from the region, and perhaps the world, also contribute to emissions in the city. Even though they are located outside the geographic boundary. These goods may include energy, materials and information. Other elements such as tourism, that supply some cities with important income, also contribute to emission. The point is that it is difficult to know where to draw the line for included emission. The article defines three scope levels; scope 1- Internal Emission, scope 2 - Core External Emission and scope 3- Non-core Emission. Figure 1.1 shows the core and non-core activities contributing to emission, the emissions geographic coherence, and how the emissions are divided into each scope.

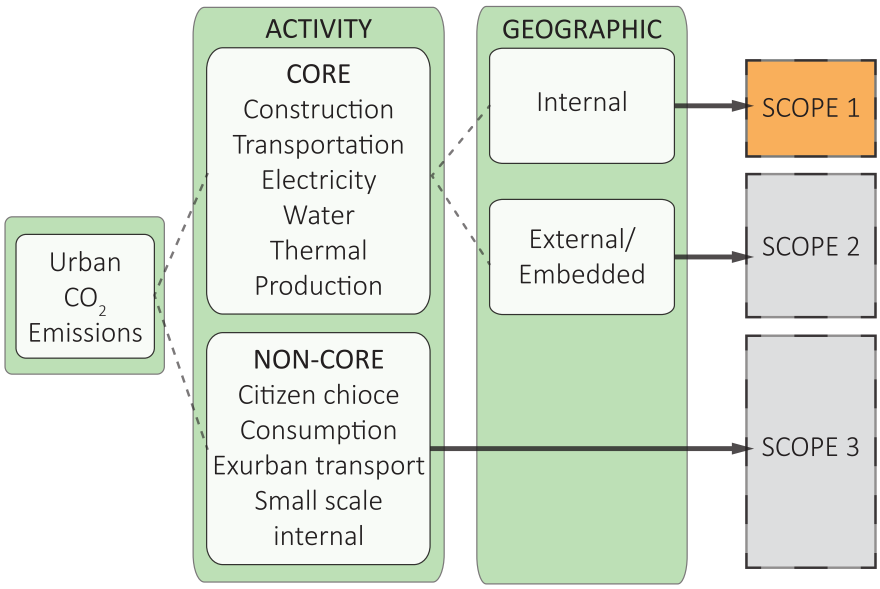


Figure 1.1: Urban carbon dioxide emission scopes, based on Kennedy & Sgouridis (2011)

Incorporated in the first scope are the emissions from production, construction, transportation, household electricity usage, on-site power generation, and waste and water management within the boundary of the city. Scope two includes imported electricity and water, waste and water treatment plants, and production located outside the city boundary.

As earlier mentioned the carbon emissions linked to a city can also include production of goods that are produced in another part of the world. These kind of emissions are included in scope three. Other elements that are included in scope three are employees that commute to the city, private goods that are purchased outside the city, and imported food products. Private usage of fossil fuels for recreational activities, and small internal CO_2 emissions from neighborhood activity (for instance barbequing) are other examples (Kennedy & Sgouridis, 2011).

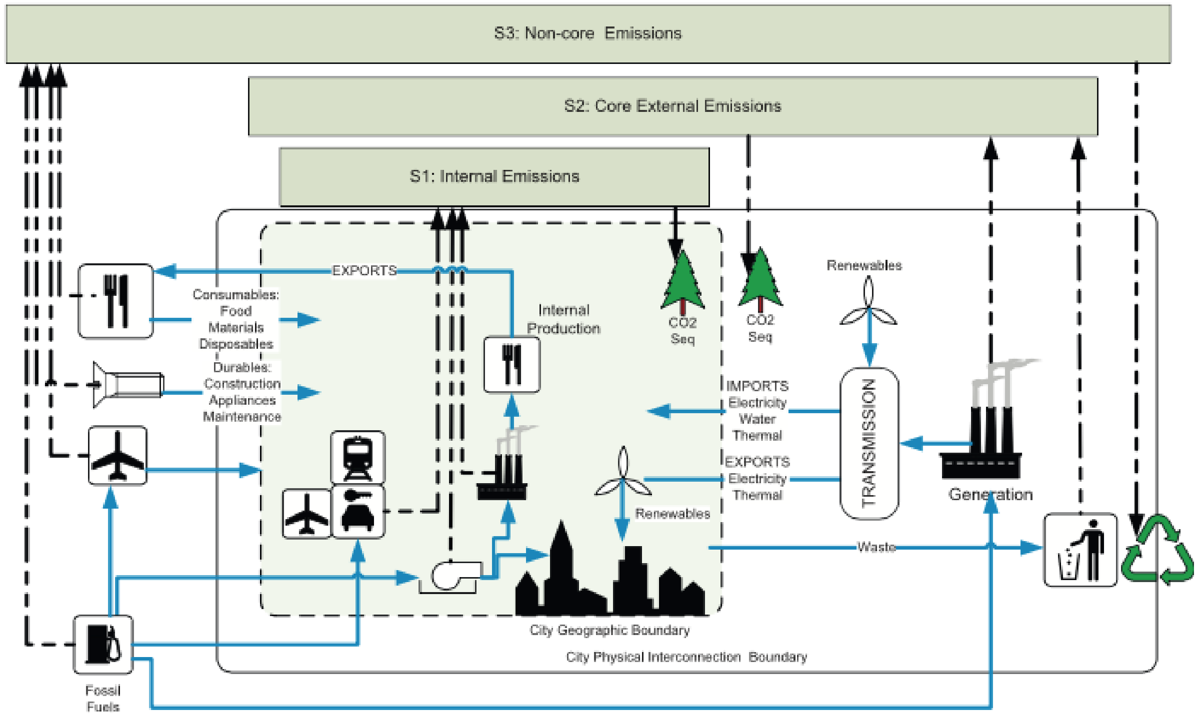


Figure 1.2: Urban scale emissions scoping (Kennedy & Sgouridis, 2011)

Figure 1.2 illustrates the three different scopes, what is included in each of them, and the city´s geographic and interconnection boundary. After much consideration it was decided that the scope of this thesis only will include the elements in scope 1 and some parts of scope 3. Even though that means excluding some parts that are also relevant for a city´s emissions. This means that the elements that will be analyzed in this thesis are within the city´s geographic boundary. Different elements that are related to the development in Masdar City that are located outside its borders are therefore excluded. In Masdar City this means excluding the carbon capture and storage plants that are going to balance the emissions that are inevitable. The power generation facility that runs on gas and solar heat (SHAMS 1) located outside the city is also excluded. Off-site waste and water treatment plants are excluded, and so is off-site construction, imported goods and food etc.

Transportation to and from the city will be included due to the large areas dedicated to parking and the amount of planned commuters. Consumption of energy, water and waste is also included. This is because some features within the city borders are directly related to the reduction of energy and water consumption. Secondly, because the goal of becoming zero waste, includes reduced consumption.

The scope of the thesis is also limited in time by only considering what has been built within the city's boundaries until now, when the observations of the city were conducted. Current development will be measured against the city´s original goals to figure out if the development is according to the plan. Elements of the city that is planned to be constructed later is excluded from the evaluation of relevancy to Norway.

1.4 Outline - thesis structure

Figure 1.3 shows how the thesis is structured, which parts that influence each other, and which chapters that are part of the analysis and theory. Theory is included in chapter three and some parts of chapter four. The analysis starts in chapter three and is more detailed in chapter four and five.

Chapter two describes the used methods in this thesis, and explains how and why the methods are used. The chapter also discusses how the main thesis table is constructed, and how it is used to analyze Masdar City and the city´s relevancy to Norway. The table is used in chapter three, four and five.

Chapter three describes Masdar City plans and compares them to relevant urban sustainability theory. The chapter is divided into four parts. Part one is an introduction to the United Arab Emirates and Masdar City. Part two, city planning and urban form, describes what measures that make the urban form sustainable, and how or if these are part of the Masdar City plan. Part three, city metabolism, describes relevant theory for city resource management, and how these measures are applied in Masdar City plans. Part four is a concluding remark on how Masdar City plans are related to relevant theory.

Chapter four is a detailed study of what has been developed in Masdar City as of spring 2015. The conducted measures are compared to original plans, and analyzed to figure out if the measures are working as intended. The chapter is divided into three parts. Part one describes what has been realized within urban form, and part two within city metabolism. Part three is a concluding remark describing the conducted measures in Masdar City and how they relate to the original plans.

Chapter three and four form the basis for chapter five, the analysis of relevancy to Norway. The chapter investigates which parts of Masdar City that are relevant for development in Norway. The city planning and urban form, and the city metabolism, are evaluated in the same order as the two previous chapters. A conclusion is drawn in chapter 6, that answers the thesis question.

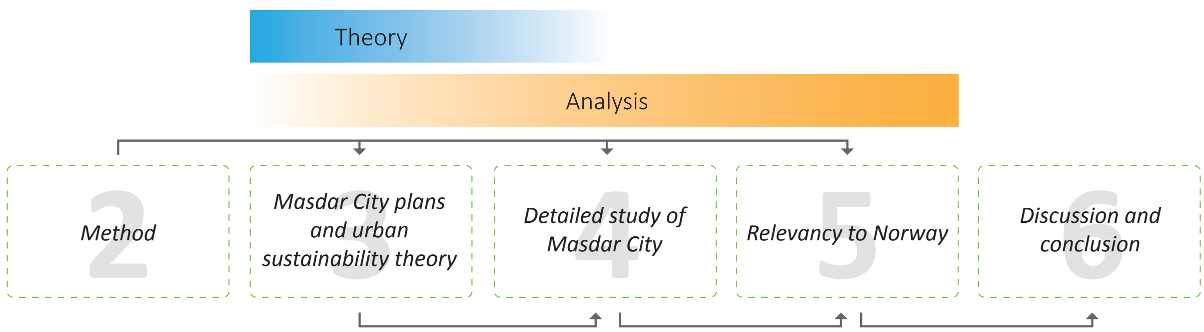


Figure 1.3: Thesis structure (I. Moxnes)

2. Method

The thesis is evaluating, meaning that information is systematically gathered and analyzed. Figure 2.1 shows how the theory of urban sustainability, the literature study and the observations are combined to form parameters that can be compared to Norwegian city planning.

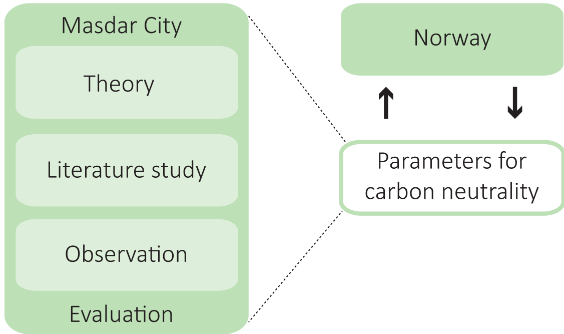


Figure 2.1: Thesis method, based on Salicath (2013)

Different literature is used to gather information about the city. Information is found through internet searches, articles and books. Articles regarding the development of Masdar City are used to get background information, to categorize how the city is structured, and what technologies are used. The same method is used to obtain information for discussion about relevancy to Norway. The usage of other researchers' literature give the thesis several perspectives because the gathered information have been collected by many different people. By comparing and analyzing different researchers´ work, it became possible to gather qualitative information that can be seen as reliable.

The literature study is supplied and edited through observations of Masdar city. The observations took place over three days. Two daytime observations and one evening observation were conducted. Looking at different parts of the city separately, and evaluating characteristics, strengths and weaknesses, was an important part of the observations. Afterwards the city was observed as a whole to discover connections. The observations were documented with mappings, conceptual drawings, pictures and videos.

Through the observations new information was collected from a different perspective. This information was interpreted, scrutinized and combined with already gathered information to gain a broader perspective. The observations made it possible to validate or falsify information that had been gathered in the literature study. In this way it became clearer what city measures that were working as intended. Observations provided the thesis with valuable information that could not have been collected through literature. This is because sensing, listening and visualizing the contents and borders of the city would have been impossible without visiting.

The thesis uses interviews as research method to a limited extent. One of the reasons for this is that broader information can better be collected by conducting literature reviews. A second reason is that some people were hard to make contact with, and did not reply to requests. It would for instance have been informing to get an interview with Masdar Initiative, the company building Masdar City, but after several emails and phone calls it became clear that this was not possible.

Strategies to become a low carbon city		
Main category	**Sub-category**	**Minor groups**
Sustainable city planning and urban form		
	Equal focus on environment, equity and economy	
	Sustainable urban form	
		High density
		Good public transportation system
		Short travel distances
		Limited sprawl
		Short distances to surrounding areas
		Easy navigation
		Pedestrian/bicycle friendly
		Mixed use
		Low rise
		Design for micro climate
		Developed on suited land areas
		Inclusion of natural elements
Circular city metabolism		
	Zero waste, sustainable materials and water	
		100% resource recovery from waste
		Zero landfill and incineration
		100% recycling of waste
		Extended producer and consumer responsibility
		Behavior change and sustainable consumption
		Treatment and recycling of water
		Use sustainable and recycled materials
	Renewable energy	
		Photovoltaic (PV) solar panels
		Concentrating solar plant (CSP)
		Windmills etc.
	Smart building design - energy and water consumption	
		Energy efficient
		Reduced water consumption
		Monitoring and control systems
		Using natural airflows
		Features to increase awareness and decrease consumption

- 3 *Masdar City plans*
- 4 *Masdar City reality 2015*
- 5 *Relevancy to Norway*

Table 2.1: Categories for thesis evaluation, and structure for each chapter (I. Moxnes)

Table 2.1 shows the different strategies to become a low carbon city that are evaluated in chapter three, four and five. The two main categories and five subcategories are constructed with the basis of Masdar City goals. Additionally, measures that are considered as necessary (within urban sustainability theory) to achieve these goals are used to make the minor categories. The table´s two main categories are; sustainable city planning and urban form, and circular city metabolism.

Sustainable city planning and urban form is divided in two subcategories:

1. *Equal focus on environment, equity and economy*
2. *Sustainable urban form*

Sustainable urban form has 12 minor groups that are developed according to sustainability theory on urban form. This means that Masdar City´s goal is to build a city with a sustainable urban from, and the different measures to achieve this are obtained from relevant theory. The city´s goal is in this way combined with theory, which makes it possible to evaluate the goals.

Circular city metabolism is divided in three subcategories:

1. *Zero waste, sustainable materials and water*
2. *Renewable energy*
3. *Smart building design - energy and water consumption*

The three categories have seven, three and five minor groups, respectively. Zero waste, sustainable materials and water is Masdar City´s goal, and the seven minor groups describe how the goal is achieved, according to relevant theory. The same goes for the next categories. The minor groups in renewable energy do however only include the planned technologies in Masdar City. This is because it is irrelevant to include all possible options for renewable energy when these are not present in the Masdar City plan.

Chapter three, four and five are all structured according to the main categories and subcategories in table 2.1. Each chapter is finalized with a table that summarizes the measures and conclude if these are present/relevant. The conclusion is a yes/no answer to the different minor groups, and a score in each subcategory. A full score in for instance smart building design will be five out of five possible "yes" answers in the minor groups.

Chapter four have sub-tables occurring after each subcategory. These are used to evaluate what measures that are for/against a yes/no conclusion. The answer to the analysis in these tables are summarized in the main table (like table 2.1) in the end of the chapter.

The score obtained in the subcategories are nonetheless not a reference or indicator on what measures that matter more to become a low carbon development. Figuring out how much each minor group matters in terms of emission is hard to measure and quantify. Both because this vary from city to city, and because emission numbers for all the different minor groups is hard to collect and would require substantial research. The score is simply a measure on how many of the minor groups that are included in the plan, is a reality in 2015, and are relevant to Norway.

3. Masdar City plans and urban sustainability theory

Masdar City has acquired much attention for claiming to be the answer to urban sustainability planning (Cugurullo, 2013). The chapter is a study of the city´s original plans, compared to relevant theory.

3.1 Introduction to the United Arab Emirates and Masdar City plans

Masdar City is located in Abu Dhabi in the United Arab Emirates (UAE) on the southeast of the Arabian Peninsula (see figure 3.2). Figure 3.3 displays where Masdar City is located relative to Abu Dhabi, and that the city is surrounded by desert landscape. The non-democratic country (Reiche, 2010) consists of seven emirates, and Abu Dhabi is one of them. The population in UAE is currently about 9.5 million people, where only 13 % of these are nationals (World Population Review, 2015). The population do not pay taxes to the government, and all hospitals, schools and other goods are therefore private (Al-Maktoum, 2015). This means that development in terms of the collective good is of lower priority, and that economic development is of high priority both in the government and with the citizens.

According to Cugurullo (2013) the oil industry started in the 1960´s. Since then the oil production has led to an increasing wealth, and a high national gross domestic product in the region. However, the former emir of Abu Dhabi, Sheik Zayed, had a conservative and traditional approach to development. Therefore Abu Dhabi has become richer instead of becoming famous like Dubai. The current emir, Sheik Khalifa, is trying to turn the region in to a more modern and globally competitive economy (Cugurullo, 2013). Abu Dhabi holds 5,8 % of the world´s total oil reserves (Helledal, 2014), and is globally the tenth largest oil producer (Cugurullo, 2013). This means that the region has almost 12 times as much oil as Norway, with only 0.5 % of the total oil reserves. Nevertheless, the United Arab Emirates was also the third largest producer of concentrated solar power in the world in 2013 (Helledal, 2014).

The culture in the United Arab Emirates is based on Arabian culture that comes from Persia, India and East Africa. The Arabian culture has influenced the local architecture, and is an important part of the country´s identity (Wikipedia, 2015u). Recent development in Abu Dhabi has however made room for newer and modern architecture with skyscrapers and towers (Cugurullo, 2013). The urban development in the country has evolved around the car, and the distances between different neighborhoods are in general great. As seen in figure 3.1, the buildings are tall, skyscraper structures surrounded by wide highways that are impossible to cross for pedestrians.

Figure 3.1: Person trying to cross a highway in Dubai. Skyscrapers in the background (Gehl, 2010, p. 55)

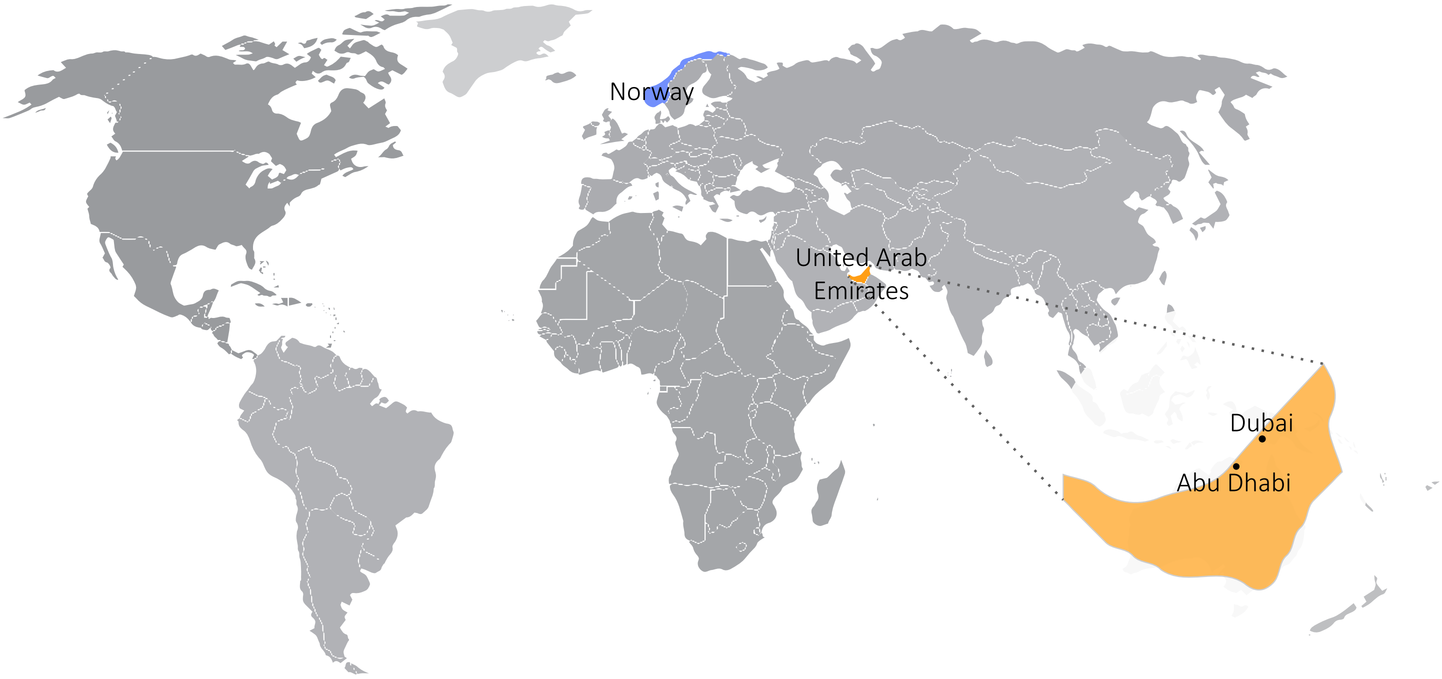


Figure 3.2: World map displaying Norway and the United Arab Emirates (I. Moxnes)

Figure 3.3: Map displaying Abu Dhabi and Masdar City (Google Maps, 2015)

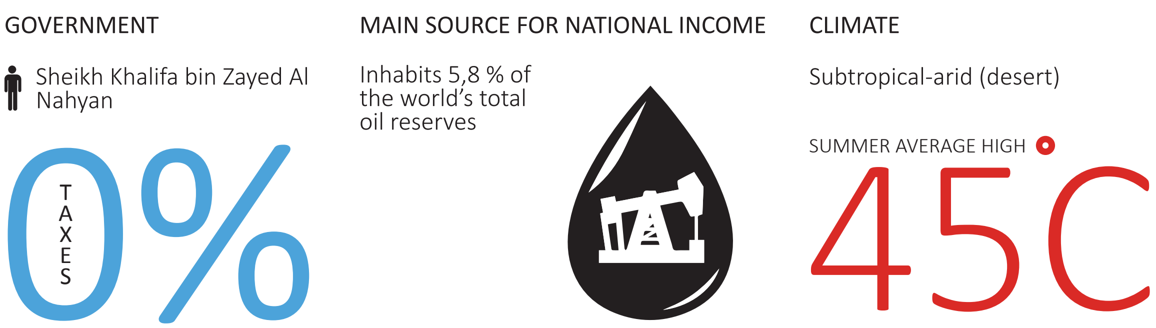


Figure 3.4: Facts about the United Arab Emirates (I. Moxnes)

The climate in the country is subtropical-arid, and wide desert dunes characterize the landscape. During the summer the temperature can reach 45 to 50 degrees Celsius, whilst the winter temperatures are like Norwegian summers, with an average of 25 degrees Celsius. The country has an annual rainfall of less than 120 mm in the coastal areas. These rainfalls occur in short periods during the summer, and sometimes cause floods. Dust storms are common and can reduce visibility severely (Wikipedia, 2015u).

Due to climatic conditions the country is facing some challenges that might change their current wealth. Fresh water is for instance a limited resource, and the increasing population will make it difficult to meet the demand (Cugurullo, 2013). Even though the Emirates claim to have enough oil for the rest of the century, climate change and changing oil prices have made the future of oil production more uncertain. Together this make the emirates face several challenges in the coming years, and one of their pioneer projects to face these challenges is Masdar City; a carbon neutral and zero waste city.

Unfortunately, the project had to adapt to the financial situation in 2008 and several cuts were made in the budget. The city was originally planned to be finished in 2016, but the adjustments moved the deadline to 2025-2030 (Cugurullo, 2013). The cuts edited the project goal from being zero carbon into being carbon neutral. The definitions of the two vary, but the main difference is that a zero carbon development does not emit carbon, and all industries have to run on zero carbon emitting energies (Carter, 2014). Being carbon neutral means that carbon is emitted, but by offsetting these emissions the development becomes carbon neutral. Offsetting means to for instance use carbon capture storage, or buying carbon credits that will be used to fund projects that reduce carbon emissions elsewhere (Wikipedia, 2013). Producing and exporting low carbon goods, like solar panels, can also be done to balance emissions (Kennedy & Sgouridis, 2011). Low carbon is an edited version of the zero carbon expression. It means that measures are made to reduce carbon emissions to a minimum without the usage of offsetting.

Due to the budget cuts several adjustments were made, and some elements in the project were shelved completely. The original water cleansing facility, that was meant to make the city self-sustained with water, is one of these elements. This means that the original plan for Masdar City has been altered and compromised. Carbon capture storage, export of solar panels, and investment in renewable energy projects are now part of Masdar City´s plan to become carbon neutral. This means that many measures to reduce emissions are outside the city´s geographic boundary.

3.2 City planning and urban form – management of land areas

3.2.1 Equal focus on environment, equity and economy

According to Bollet and Demarle (2015) one of the thoughts behind the project is that social (equity), economic and environmental considerations should all have an equal part in the master plan for Masdar City. The thought behind the concept is consideration for many different areas that are worth caring about in urban planning. It is a holistic approach that recognizes that there are many values that need to be balanced to achieve sustainability. A good starting point is to focus on elevating the considerations for environment and equity to the same level as economy in day-to-day decisions (Wheeler, 2013, pp. 63-65). If managed, an equal focus on environment, economy and equity would according to Campbell (2012) be ideal. However, balancing the three is not simple to achieve in real life situations.

Campbell (2012) claims that most planners end up focusing on only one of the three because they are limited by professional constraints and opposing interests, for instance the interests of authorities and bureaucracies. The economic development planner evaluates the city according to areas for innovation, production and consumption. There is always market and industry competition with other cities, and urban space is considered to be market areas, commuter zones and highways. The environmental planner considers the used resources and produced wastes from the city as a threat to nature, and nature is therefore the city´s main competitor. Urban space is ecological places as green areas and water. The equity planner sees the urban environment as a place for opportunities, services, and distribution of services. The differences between social groups pose the greatest competition. Urban space is communities, neighborhoods, and other places for social activity (Campbell, 2012).

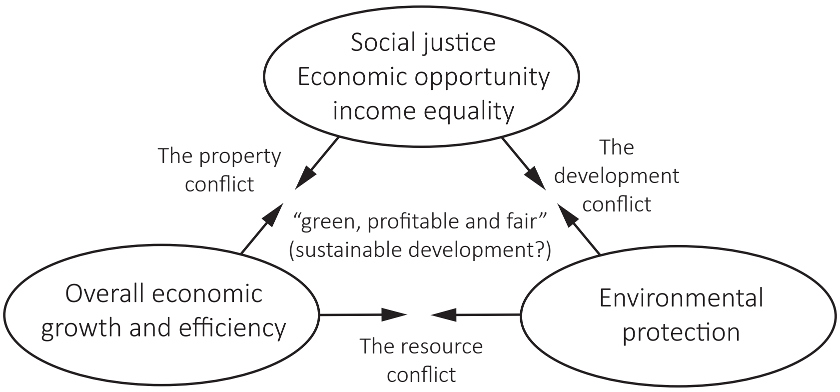


Figure 3.5: Conflict areas between equity, environment and economic considerations (Campbell, 2012)

Figure 3.5 shows the conflict areas between equity, environment and economic considerations. The conflict between economic growth and social justice arise from the competition between different groups, and property management. For instance the opposing interests between company leaders and employees, or landlords and tenants. The conflict is complex because the two opposing interest's disagree on the relational terms, and at the same time they need each other to exist. The contradiction in the capitalist democratic community is the definition of property as private whilst at the same time relying on involvement from the government for maintaining valuable social aspects of the properties (Campbell, 2012).

At the same time the resource conflict between economic growth and environmental protection represent the opposing interests of preserving the nature and exploiting its resources.

Businesses want to have limited resource access to achieve economic benefits, but at the same time they need to preserve resources for future needs. In the end there must be left enough natural resources for reproduction, which again leads to the discussion on how much is enough (Campbell, 2012).

The development conflict is located between social justice and environmental protection. It evolves around how to protect the nature and how to increase social equity at once, regardless of the city´s economic conditions. If choosing environmental protection reduces economic growth it affects the people at the bottom of the society the most. Some even argue that environmental protection is a luxury that only the wealthy can afford, and this assumption is the center of the development conflict. Poor urban communities are often forced to make unfortunate choices between economic survival and environmental quality. One example is that economic possibilities often present themselves in industries that are toxic and harmful to the environment (Campbell, 2012). "Not in my backyard" describes the opposition of residents in communities protesting for unpopular development in the US, for instance against landfills or a jail. These developments are often placed in poor communities because rich communities can afford to protest and use their land for more community friendly purposes (Caves, 2012).

In other words, if the goal is to achieve an overall more environmentally sustainable society, both equity and economy need to be considered as well. Creating a livable city will give people the opportunity to live, work and enjoy themselves at the same place. Reduced travel distances, for instance for work and cultural activities, reduce emissions from traffic. It also give people the opportunity to choose walking and bicycling instead of driving. Diversity in the city will increase opportunities and make the environment more exciting. Which again will inspire people to use the urban spaces (Wheeler, 2013). This means that the Masdar City goal of considering all the three mentioned aspects is an environmentally smart goal that can contribute to reduced emissions.

"I'm not a big fan of capitalism or business, but it's pretty obvious that if we build a beautiful system of bike boulevards, bicyclists will come to ride them by the tens of thousands. When they do, they spend a lot of money and keep a lot of our local economy going."

Chris Carlsson

As the statement suggests, building something that receives a lot of attention will give economic benefits. The plan is to attract approximately 1500 different companies to have their office buildings in Masdar city. To achieve this goal the city is going to be a free zone where the companies do not have to pay taxes (Reiche, 2010). The buildings will be used as permanent showrooms for new technology, and are therefore much more than ordinary houses. In this way investors and visitors may actually see what they can buy. This is meant to attract new developers and people, who again will continue the development of the city (Cugurullo, 2013).

Cugurullo (2013) claims that the social part in Masdar City has already been lost when compared to the economic aspects, which means that the environmental aspects might be affected as well. He claims that the city is an example of a business and commercial enterprise, with economic development in Abu Dhabi as purpose. The United Arab Emirates are known for their impressive architecture, and development is often affected by the need to impress the outside world. Masdar Initiative, the company responsible for construction, is run by the government. Their interest for economic development in the region might be the leading factor for the choices made (Cugurullo, 2013). The reality of considering the economy, the environment and the equity is further discussed in chapter 4.3.

3.2.2 Sustainable urban form

Figure 3.6: Rendering showing the completed Masdar City (Foster + Partners, 2007)

Figure 3.6 shows a rendering of the city when it is completed. When finished, Masdar City will be 6 km^2, and is planned to have room for 40,000 residents, and 50,000 commuters (Bollet & Demarle, 2015). Wheeler (2013) uses the work of Kevin Lynch to form five land use and urban form values that are important for sustainable city planning. A sustainable city is in his opinion likely to be compact, contiguous, connected, diverse, and ecological (see figure 3.7) (Wheeler, 2013).

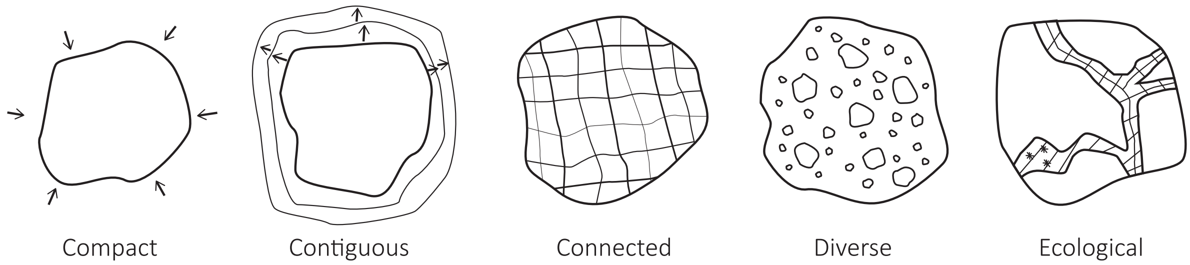


Figure 3.7: Characteristics of a sustainable city (Wheeler, 2013, p. 141)

Comparing figure 3.6 and 3.7 shows that the planned development in Masdar City have similarities with figure 3.7 displaying ecology, diversity, connectedness and compactness. Masdar City is planned to be a compact, low-rise city with high density, and no urban sprawl (Foreman, 2007). According to Wheeler (2013, p. 138) a compact city will have a positive effect on both the environment and the economy. A sprawling city will spend more money on building necessary infrastructure such as roads, sewers, and water supply infrastructure. Both the construction of these facilities, and the increased travel length for inhabitants will lead to increased emissions. A large city footprint will also affect the surrounding environment by depleting natural resources, and occupying land that could be used for agricultural purposes.

As seen in figure 3.6 the planned area for Masdar City has a strict border. Since the city is planned to be low rise, it means that there will be no growth neither outwards nor upwards. This again means that the city will have a nearly constant population, only exchanging people in existing buildings. Though unlimited sprawl is considered to be unwise in city planning, growth or change, is however inevitable and necessary. Cities are, as earlier mentioned, complex and constantly changing organisms that need to develop in order to evolve and continue their existence. It can therefore be questioned if sustaining the city border and building height in Masdar City is realistic. Market forces and changing desires, needs and requirements make it almost impossible to sustain a "fixed" development. Another challenge with such a development is population variety. If the demand is pressured and growth is restricted, the housing prices will accelerate. This again means that the population in Masdar City will increasingly exist of high-income families.

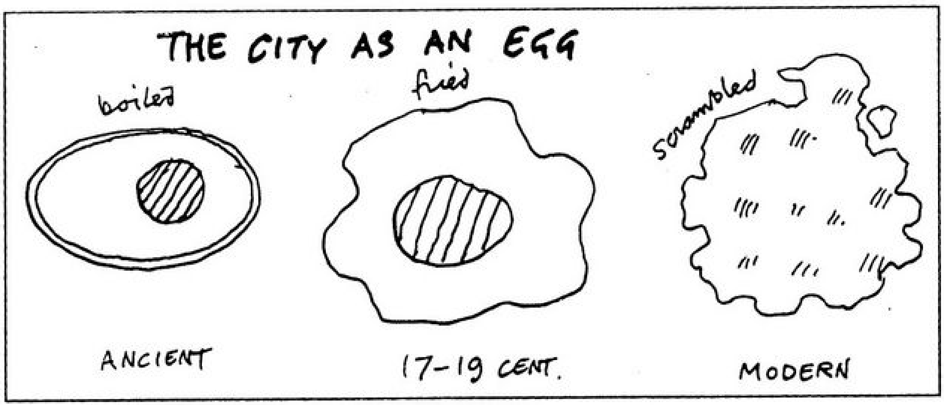


Figure 3.8: The city is an egg (Price, 1982)

Cities developed in earlier centuries were in general smaller and planned for people due to the low urban population and a car free environment. As seen in figure 3.8 ancient cities had a compact core, and a clear edge. In the 17^{th} to 19^{th} century the core was still compact, but the edge was more irregular. Modern cities are compared with a fried egg, with several centers and an unclear edge. When cities grow they become increasingly polycentric, and travel between different parts of the city increase along with the distances. Masdar City´s medium size is therefore a well-considered choice for maintaining qualities that make a city more sustainable and emit less carbon dioxide.

A compact and dense city model will also have the opportunity to build an efficient public transit system. Bertaud (2004) claims that 30 people per hectare is the minimum requirement to make a public transit system efficient, and according to Duany et al. (2000) 40 to 70 people per hectare is required. There are in other words split opinions on how dense a development needs to be. It is however certain that a number of people need to live within walking distance from the transit stop. Only then will the public transit system be economically sustainable. The population density in the finished Masdar City development will be 66.7 people within each hectare with 40,000 inhabitants. Barcelona (one of the densest cities in Europe) has a population density of 159 people per hectare, and Oslo´s density is 14 people per hectare (Wikipedia, 2015c, 2015m). Being a medium sized city, Masdar can be considered as dense, and according to earlier mentioned definitions, planned density should be enough to sustain a public transit system.

According to the original plans of Masdar City, a Personal Rapid Transit (PRT) system was planned to cover the whole city. The city was therefore planned to be built on 7.5 meter high pillars, with the PRT system running on the ground, and underneath the city (Cugurullo, 2013). Nonetheless, due to earlier mentioned budget cuts, the system was shelved for large parts of the city. The current plan only includes development of the PRT system in a small area (further discussed in chapter 4).

Figure 3.9: Personal Rapid Transit (PRT) vehicle with measurements (Kimball, 2010)

The PRT is an automated and driverless system that is available on demand, and is supposed to be available at all times. Figure 3.9 shows the vehicles that are 3.81 meters (12.5 feet) long and 1.95 meters tall (6.4 feet). According to Mueller and Sgouridis (2011) the vehicles are electrically powered, use lithium batteries, and energy generated from solar panels. They travel directly from origin to destination and can transport up to 4 people. The vehicles are also individually hired and you can chose to travel alone or with other people. Constructing the system under ground has some advantages. Path crossing with pedestrians is for instance eliminated, and the system is not a visual intrusion in the streets above. Masdar City is also planned to be a car free development, only relying on public transportation. The result is that noise pollution and congestion from cars on street level is eliminated, and the infrastructure footprint is reduced (Mueller & Sgouridis, 2011). These advantages are elements that according to Gehl (2010) are important to create a city for people. There will not be any cars creating barriers and obstacles, and streets that are walkable and safe for pedestrians is the result.

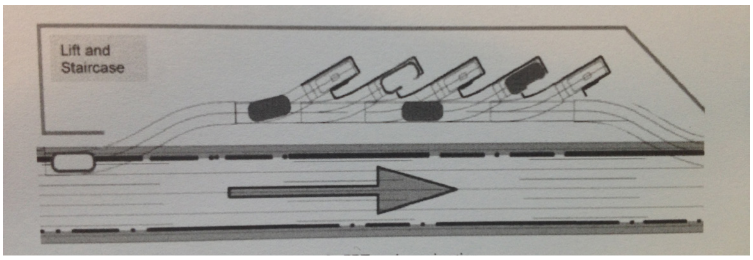


Figure 3.10: PRT station animation (Mueller & Sgouridis, 2011)

The PRT system runs on a network of tracks, and is guided by magnets below the ground and fiber optics over the ground (Gunther, 2011). It was planned to have 8 lanes at the central spine, and the other lanes would have four one-way lanes where the two in the middle ran faster than the two on the sides. The PRT stations will have 5, 6 or 12 berths placed next to each other as displayed in figure 3.10. This means that the vehicles can enter, embark passengers and leave independently from each other. The system is also supposed to work as a freight system, which means that some vehicles will collect and transport waste and goods. These are called Freight Rapid Transit (FRT). The FRT is supposed to share tracks with the PRT, but have other stations for loading and unloading (Mueller & Sgouridis, 2011).

Contiguous urban form means that city expansion takes place next to existing areas. New development will naturally be connected to existing infrastructure, and long roads between disjoined developments are avoided. According to Jain (2009, p. 25) "the main problem with cities today is that they have become centers of mobilization rather than civilization. They are nodes of an increasingly intense economic activity, with the volume of travel having reached unprecedented levels in recent years". Despite the positive sides with the medium sized development in Masdar City, the uneven number of workspaces and planned number of commuters conflict with the thought behind the project. In the 1960ties, when the car first evolved, city planning changed and became increasingly focused on cars instead of people. Shopping malls were developed outside city centers surrounded by large parking areas. People had to drive to the shopping malls, and distances to surrounding areas made a challenging environment for pedestrians. Even though Masdar City is not a shopping mall, the planning does have similarities with the 1960ties car planning. The city edge will consist of large parking garages, and 50.000 commuters are planned to work in the city.

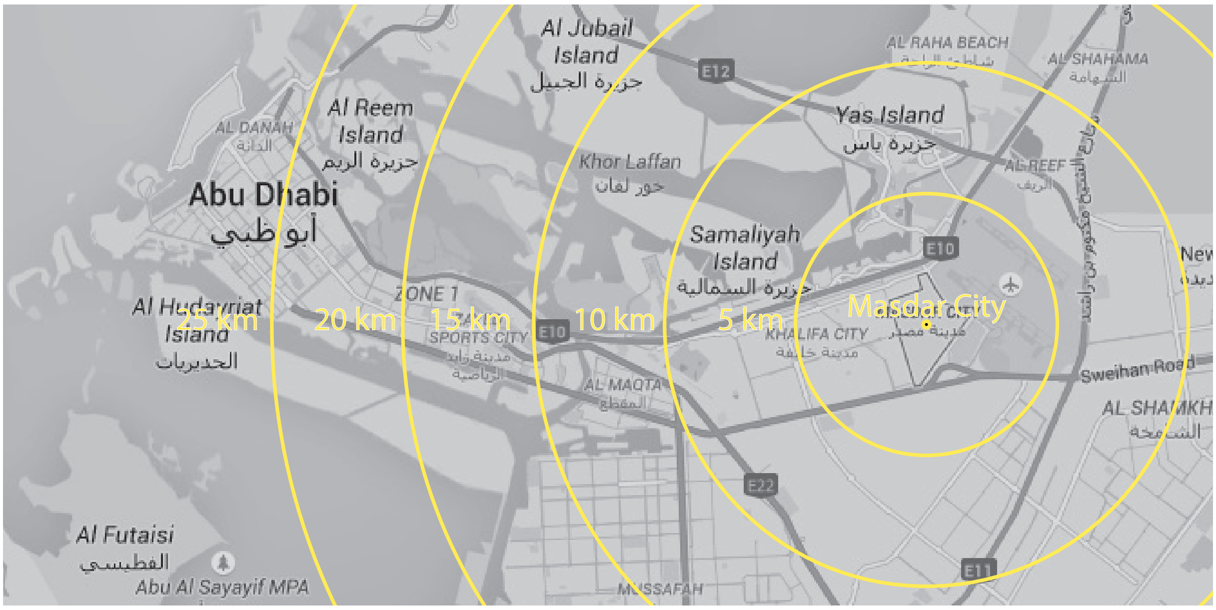


Figure 3.11: Distances to surrounding areas (Google Maps, 2015)

Figure 3.11 displays Masdar City and distances to surrounding areas. The city is located next to other residential areas, the Abu Dhabi airport, and 25 kilometers from the city center of Abu Dhabi (30 minutes to drive). The distance from the city to Dubai is 120 kilometers, and the travel time by car is approximately 1.5 hours. The distances to the main urban areas in the region are in other words large, and the commuters will contribute to extensive traffic. If traveling by car these commuters will emit a significant amount of carbon dioxide, and the parking garages will give them the ability to do so.

According to Wheeler (2013) the urban form can be described as connected if the streets and paths are well linked, and it is easy to find your way in the city. Visual elements, like landmarks, are elements that increase a city´s connectedness. Figure 3.12 shows the planned street system of Masdar City. According to Endpoint (2008), who helped plan the street system, convenience for the users was the key priority when planning. The network is planned with circulation routes, landmarks, and smart information points throughout the city. The dark blue lines indicate pedestrian and bicycle pathways, the light blue lines indicate pedestrian pathways, and the green lines are urban parks. The black, curved line is the planned urban light rail system that will connect the city to neighboring areas (Endpoint, 2008). The corridor will function as the main transportation and infrastructure axis. The campus area, public parks, retail and cultural activities are planned to be located alongside the corridor (Foreman, 2007).

Figure 3.12: Planned street system in Masdar City (Endpoint, 2008)

The diversity of a city is measured after how mixed the land use is, architectural variety, and pricing options for the inhabitants. Masdar City is intended to be a mixed-use development with low-rise buildings. According to Lynch (Wheeler, 2013, p. 142), the elements should preferably be mixed together at a small scale, otherwise the development becomes homogeneous. This type of urban form often results in segregation between different social groups, larger driving distances, more congestion, and air pollution. Mixed use development, on the other hand, often leads to vibrant and attractive communities, where air pollution is reduced because the distances between areas are shorter (Wheeler, 2013). However, it is not certain that people choose to work at the same place as they live. It is therefore especially important with correspondence between number of workspaces and the number of city residents. The number can be seen as uneven since Masdar City plans to have 50,000 commuters. Another important element within diversity is planning cities after the human scale. Streets need to be perceivable and visible to create livable and walkable communities, which means that buildings over 5 stories are too tall (Gehl, 2010, p. 50). All buildings in Masdar city are planned to be 4-5 stories high.

Figure 3.13 shows the master plan for Masdar City. The plan displays the light rail system, metro line, and future city entrances. Offices will be located in the city core, whilst townhouses and apartments will be located around the core (yellow areas). Two green corridors, and park areas around the city, will provide the residents with recreational opportunities. The area around the city is also planned to be used for research activities and energy production. The large gray area next to the main western entrance is the already built solar panel facility. The development started with the area marked as educational/institutional, which is the Masdar Institute of Science and Technology (MIST). There are no areas for local food production in the master plan.

Figure 3.13: Masdar City master plan (Masdar Initiative, 2014, p. 90)

Figure 3.14 displays planned land use percentage in the finished city (Foreman, 2007). The figure shows that 30 % of the city will be for housing, and only 19 % of the area will be for transportation. In conventional cities the land used for transportation and parking is usually around 35 % (Gardner, 2011). Cultural buildings will occupy 8 % of the landscape, and a total of 37 % will be for commercial and economic purposes. According to Foreman (2007) the residential parts of the city will be split into smaller communities that will house 3500-5000 people each and is planned to have a public transit stop within 200 meters walking distance.

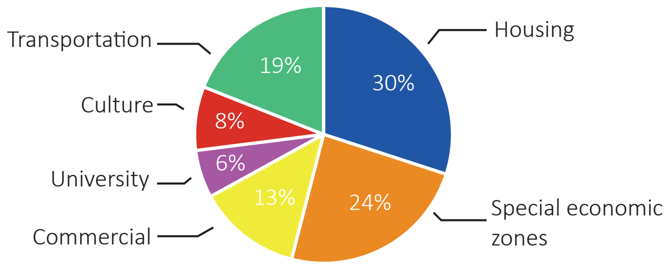


Figure 3.14: Planned area usage in the finished development (Foreman, 2007)

Planning with ecology indicates that the city should be planned with nature. Natural elements should be included in the urban form because these help preserve local ecological systems, and function as recreational areas for the city´s residents (Wheeler, 2013, p. 142). According to Jain (2009, p. 52) the usage of plants and vegetation is an important element for cooling the streets in low-carbon city planning. The green paths in the Masdar City master plan are strategically located to catch and cool the winds from the surrounding landscape. The long, narrow park areas are planned to help ventilate and cool the streets. Developing park areas in the desert will nevertheless require large amounts of water for irrigation, which again will contribute to emissions.

Planning for the micro-climate should also include maximizing shade, and minimizing solar reflection from the buildings in the streets (Jain, 2009). Masdar city will be built with inspiration from traditional Arab design. This type of design has narrow streets and external shading, and the design is therefore optimal to keep the streets shaded. The shade will make the streets cooler, and make the houses require less energy for cooling. The plan is therefore expected to handle the rough climate in the United Arab Emirates well (Foreman, 2007).

Masdar City is being developed on an earlier brownfield, and is therefore not using areas that can be used for ecological purposes, like food production (Masdar Initiative, 2014). Unstable soil and water pockets in the ground did however not present ideal development conditions. The city had to be built on pillars due to these conditions, and the PRT system could not have been built under the ground (Bollet & Demarle, 2015).

3.3 City metabolism – management of resources

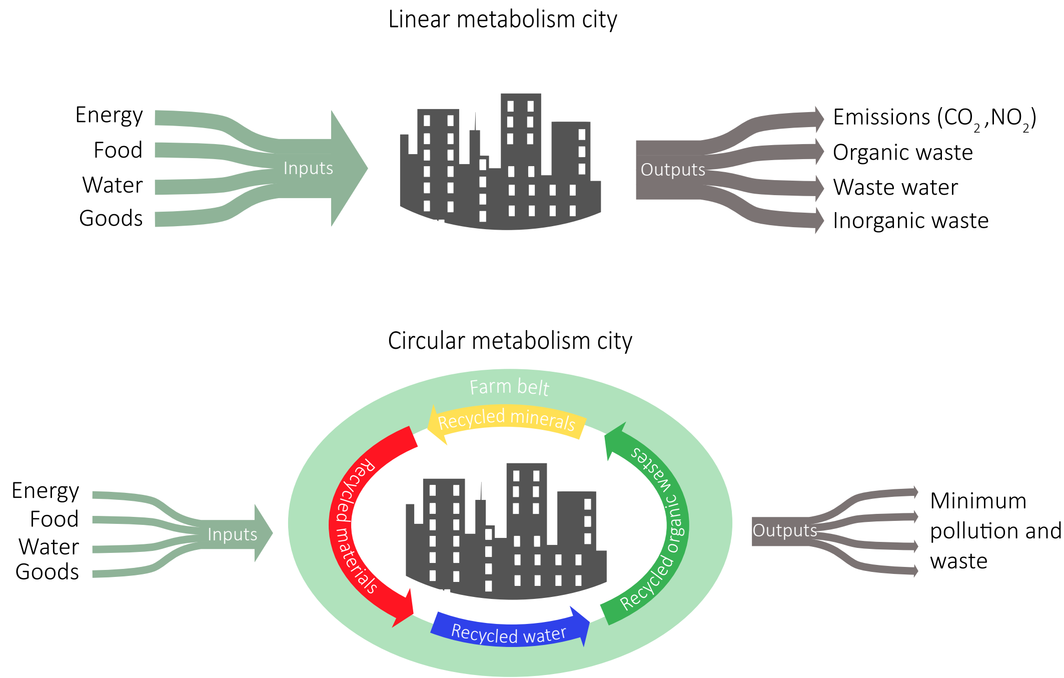


Figure 3.15: Linear and circular city metabolism, based on figure from Girardet (2015)

3.3.1 Zero waste, sustainable materials and water

According to Jain (2009, p. 27) "the metabolism of most cities is essentially linear, with resources flowing through the urban system without much concern about their origin and destination of wastes". Figure 3.15 shows the linear city metabolism where energy, food, water, and goods are city inputs used for production and consumption. Energy is mostly produced by oil, coal, and other fossil fuels that are non-renewable. City outputs are emissions of carbon dioxide (CO_2), nitrogen oxides (NO_2), organic wastes, waste water, and inorganic wastes. Few resources are recycled, large amounts of waste is produced, and the natural environment is exploited without further concern. The circular city metabolism is on the other hand nature's way of handling resources. The nature renews and sustains its environment, and the ecological system is in balance. For cities to become sustainable, the circular metabolism approach should be implemented. According to Jain (2009, p. 28) the city should obtain "harmony with nature by ensuring minimum waste". The principles of recycling, reusing, reducing and recovering are important elements, and the production system should be combined with city outputs. Figure 3.15 also shows a circular city metabolism where the inputs of energy, food, water, and goods are smaller than in the linear city metabolism. Renewable energy is produced from solar panels, windmills, hydro power etc. Materials, water, and wastes are reused and recycled, and in this way the resources capacity is maximized. Pollution and wastes produced from the city is therefore minimized. Local food production reduces long transportation distances, and a farm belt is therefore located around the city core.

Additional to the circular metabolism is Braungart and McDonoughs (2009) new way of looking at sustainability. In the "cradle to cradle" approach they claim that the current way of considering sustainability is a negative way of looking at nature and human kind. Current goals of reducing our footprint, achieving zero emission etc. imply that we should simply be "less bad" at exploiting nature. They claim that being sustainable is not to use your car less often. Being sustainable is knowing how to use the available resources in a way that makes our consumption part of the biological cycle.

As the circular metabolism they promote recycling and reusing of materials. However, they add minerals to the cycle, and claim that these should be conserved and recycled as well as materials. Waste is seen as food and nutrients. Materials and minerals with the ability of being recycled infinite times should be chosen over the once without this ability. Material science is therefore an important part of the sustainability approach. The approach differs from the circular metabolism by not looking at growth, footprint and emission as something that should be reduced and minimized. Growth is accepted, but with the right materials. They also argue that waste should be recycled and reused instead of being incinerated to obtain energy. The reason for this is that recycling protects the natural resources from depletion, and maintain the opportunity for endless recycling. Incineration of waste supplies energy and reduces the amount of waste disposed at landfill, but for long-term sustainability it is better to reduce additional depletion of natural resources (Braungart & McDonough, 2009). It can however be discussed if it is possible to recycle 100% of all wastes, and incineration is considered to be a better alternative than landfill disposal. This is because fewer greenhouse gases are released from incineration than from landfill disposal (Retursamarbeidet LOOP, 2015). Both landfill disposal and incineration release substances that are harmful to human health and the environment, but emissions from incineration can be cleaned. When harmful chemicals and substances are removed, and energy is produced, incineration is considered a better alternative than landfill disposal (Miljøstatus, 2014c).

Masdar City aims to be a zero waste city, which means that 100% of the waste should be recycled and all resources should be recovered from waste materials. This is however a challenging goal in a global economy where the consumption of goods and production of waste is constantly increasing (Zaman & Lehmann, 2011c). Masdar City aims to achieve this through controlling the materials that are used, intensive recycling, and by using a waste-to-energy plantation (Nader, 2009). An on-site composting bin is planned to dispose biodegradable wastes, and the compost will be used to fertilize plants in the landscape areas within the city. All steel, concrete and wood that are used for construction is planned to be 100% recycled. The waste is supposed to be managed and sorted in an on-site Material Recycling Center (MRC). Wood will be stored for reuse or chipped to be used in the landscape areas. Steel, plastic, and other materials will be gathered and sent to an off-site recycling center (Masdar Initiative, 2014). Emission from transportation is limited by locating the recycling facilities close to the city or within city borders. Materials provided by the surrounding environment is used for construction, and emission from imported materials is therefore limited as well (Bollet & Demarle, 2015).

However, according to Zaman and Lehmann (2011a) current approaches to a zero waste city, including the approach in Masdar City, is lacking an holistic approach to zero waste management. Figure 3.16 shows an holistic way for a city to become zero waste. They claim that behavioral change and sustainable consumption have to count for 25% of reduced emissions. Further they claim that 100% of the used resources need to be recovered from waste, and none of the waste should be sent to landfills for incineration. 100% of the waste should be recycled, and producer and consumer responsibility should be extended (Zaman & Lehmann, 2011a).

The different approaches mentioned above state that it is neither easy nor a one-way solution to the world´s resource and waste problem. How to become zero waste is also a matter of definition. Masdar City aims to become zero waste, but according to their measures it can be discussed if this is realistic. The aim is extremely ambitious. The city will for instance consume large amounts of imported electronics for business and personal usage. Recycling of e-waste, and extraction of for instance minerals for recycling (used in iPhones, computers etc.), require a lot of energy. This will give the city a large carbon depth. Incineration of the waste is also planned to be chosen over recycling. However, if not 100% zero waste, the city has planned some measures that can be seen as more sustainable than the ordinary linear city metabolism.

Figure 3.16: Holistic approach for a city to become zero waste, from Zaman and Lehmann (2011a)

According to Wheeler (2013) 25 % of all harvested wood is used for construction of buildings. Braungart and McDonough (2009) do, as earlier mentioned, promote the right usage of materials as one of the most important elements for sustainability. Wheeler (2013) mentions different sustainable building materials, and sustainably harvested timber is one of the available materials on the market. Certified timber is grown in woods with carefully established rules. Some of the rules are for instance forbidding clearcutting, demanding buffer zones, assuring replanting, and preserving a viable forest by harvesting at a slow rate. Other sustainable building materials are recycled timber from demolished buildings, steel (can be recycled and reused), recycled concrete, recycled glass, and local soil (Wheeler, 2013).

The Arab Emirates is the country in the world that has the highest consumption of water. Every day each person uses 458 liters of water. In Norway the consumption is 300 liters per day per person. The developers of Masdar City has a goal of reduction to 87 liters (Bollet & Demarle, 2015), but according to Foreman (2007) the city planners have estimated that each resident will use approximately 200 liters of water each day.

The city´s water usage will be supplied by the municipality distribution network which rely on desalination to produce water. This means that the fresh water will be produced from sea water. However, 50 % of the water will be recycled in an on-site immersed Membrane Bioreactor (MBR) sewage treatment plant to reduce unnecessary energy consumption. 10% of the water will be from sewage (black water) and 90 % will be from sinks and showers (gray water) (Foreman, 2007).

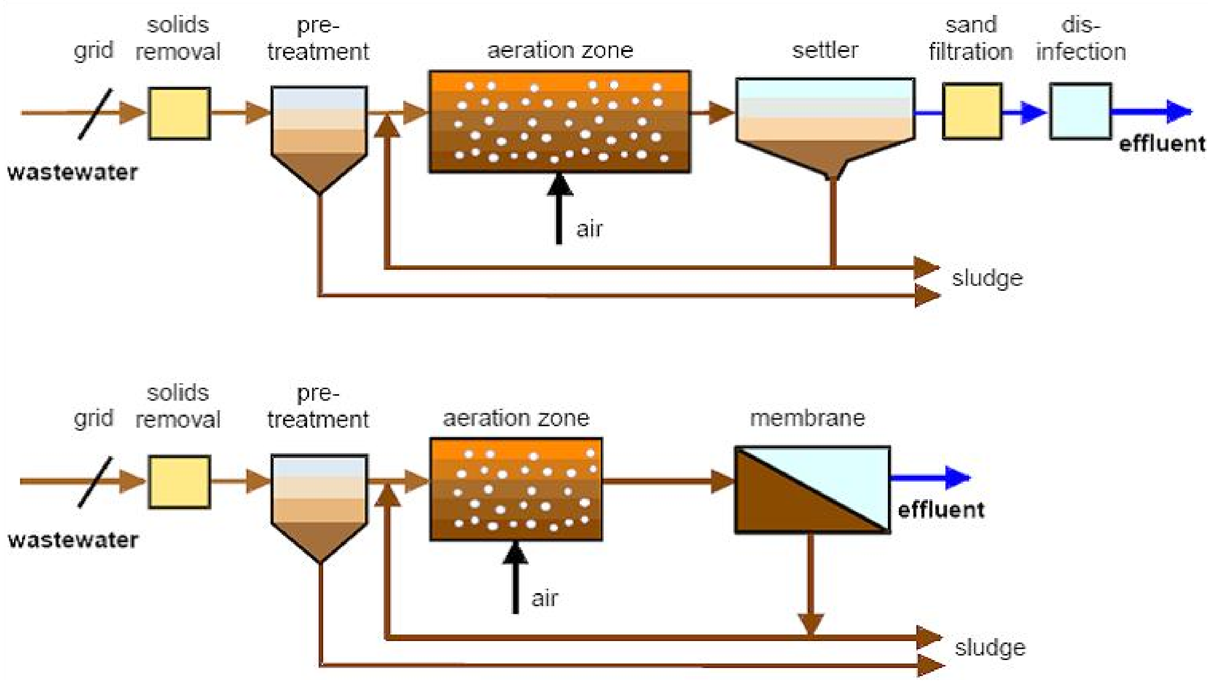


Figure 3.17: Schematic of conventional activated sludge process (top) and external (sidestream) membrane bioreactor (bottom) (Wikipedia, 2015k)

As seen in figure 3.17, the membrane bioreactor (MBR) is different from conventional water treatment plants (CAS) by using a membrane that combines the three last stages of the cleaning process, namely the "aeration, secondary clarification and tertiary filtration". Solids and large particles are first removed. Then the water is cleaned for bacteria, nitrates and phosphorus before it is fed into the membrane (Pirani et al., 2011). The revolutionary with the MBR plant is that the footprint is reduced without compromising the quality of the emitted water (Wikipedia, 2015k).

3.3.2 Renewable energy

According to Jain the main energy sources of the world are wind, water and earth. Fossil fuel is solar energy that has been preserved through billions of years. The sun converts water in to vapor, enables vegetation to grow, and helps generate oxygen through photosynthesis. The sun is therefore the only source of our past and future energy (Jain, 2009, pp. 29-30). Figure 3.18 shows a map over annual solar radiation in different parts of the world. It shows that Masdar City is located in the area with the highest amount solar radiation, where it is possible to obtain over 2200 kWh/m^2 each year. It is therefore logical that one of the most important investments in Masdar City are the photovoltaic (PV) solar panels (Reiche, 2010). 22 hectares of land at the city edge is dedicated to a PV facility that can produce 10 megawatts in full production (see figure 3.19). The facility produces approximately 17.500MWh of electricity each year. Some of the buildings in the city do also have solar panels on the rooftops that in total have a capacity of 1MW. They can produce 1.500MWh of electricity annually (Masdar Initiative, 2015).

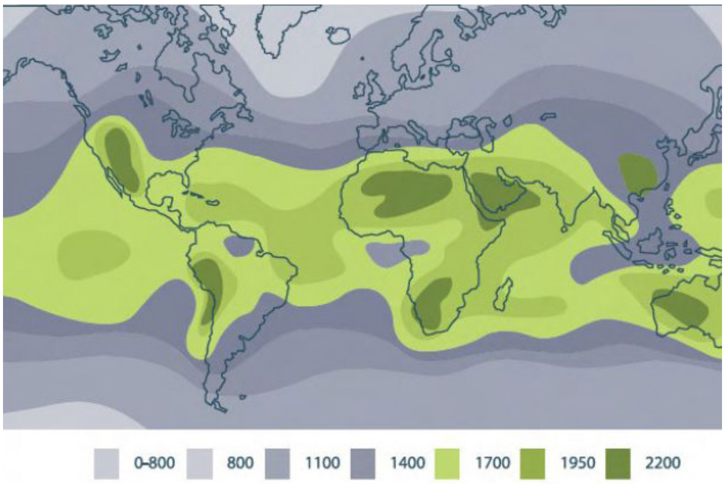


Figure 3.18: Annual solar radiation towards an optimally angled surface (average kWh/m2 and year) (Brantenberg)

Figure 3.19: The 10MW photovoltaic (PV) solar panel facility in Masdar City (I. Moxnes)

According to Boxwell (2010) solar electricity is produced by sunlight shining on photovoltaic (PV) solar panels. The sun generates large amounts of electromagnetic radiation. In quantum mechanic theories electromagnetic radiation is described as a stream of photons. The visible part of the electromagnetic radiation is called light. Light carries large amounts of energy, and electricity is generated in the solar panels by using the photovoltaic effect (absorbing photons). The electricity is generated by an electric current that occurs when certain materials are exposed to light. Two layers of a semi-conducting material are combined to generate this effect. One of the layers needs to have a depleted number of electrons. When the photons from the sun hit the layer, electrons are released, and "jump" between the layers. This creates an electrical circuit, which again creates the electrical current. The material used in solar cells is silicon. Very thin silicon wafers are cut, polished, and bathed in chemicals to create the electron imbalance. "The wafers are then aligned together to make a solar cell. Conductive metal strips are attached to the cells to take the electrical current". To make a useful amount of energy the cells are connected to make a photovoltaic module (solar panel) (Boxwell, 2010, p. 4).

Boxwell (2010) also claims that most solar electric experts believe solar panels to be cost effective only when there are no other alternatives for electricity. At least this is the case for larger facilities, because the system becomes more difficult and expensive parallel to the amounts of needed energy. This is also the case with the facility in Masdar City. Harder and Gibson (2011) conducted a study on the profits of the 10 MV facility in Masdar City, and the test displays that the costs for choosing photovoltaic panels over natural gas for electricity production in Abu Dhabi is still too high. It is therefore not profitable to choose PV panels, showing the main reason for why solar panels are not chosen for large scale production around the world (Harder & Gibson, 2011).

The solar panel facility in Masdar City is connected to the Abu Dhabi power grid, which means that the system is a grid tied solar electric system (Boxwell, 2010). In this way the solar panels can supply the grid with energy when the production is greater than the city´s usage, and receive energy at night when the solar panels are inactive (Nader, 2009).

The environmental benefits of constructing a grid tied solar electric system for a city is according to Boxwell (2010, p. 8) varying. After installation the solar panel system is a low carbon electricity generator, but there is a large carbon footprint related to the production of the panels. This is mostly due to the small amount of panels being constructed, and the chemicals used in the process. Recent years increase in solar panel production, and improved manufacturing techniques, has however decreased the carbon footprint significantly. Most producers claim that the carbon debt can be recouped within 2-5 years by power generation in solar panel systems that are not connected to the local grid. It is harder to calculate the pay-back time for systems connected to the grid, which is the case in Masdar City. It depends on how the electricity is produced in the main grid system, and whether or not the electricity production from the PV facility corresponds with peak periods of electricity demand (Boxwell, 2010, pp. 8-9).

A concentrating solar plant (CSP) is also constructed within the city borders. The CSP is different from the PV panels because mirrors are used instead of silicon wafers. The 100 kW Beam-Down Solar Thermal Concentrator in Masdar City is nonetheless different from conventional CSP (Hurst, 2012). As seen in figure 3.20, moving mirrors are used to concentrate sunlight into one specific point. Water is heated and creates steam. This steam is used to move turbines, and create electricity (Foreman, 2007). The tower directs the sunlight down in to a receiver at the base of the tower. This eliminates the need for additional energy to pump the heated water up. The facility can generate 75-85 MWh of energy annually (Hurst, 2012), and unlike the PV facility it can store energy without the usage of polluting batteries (Bollet & Demarle, 2015). The thermal energy can be stored in a salt solution, and be used to generate electricity later. Unfortunately the CSP needs a lot of space, whereas PV collectors can be placed on rooftops because they are relatively light of weight. The disadvantage with PV panels is that when the sun stops shining the energy also stops flowing, and compared to CSP it is inefficient to store PV power. Another disadvantage with PV panels is that the power is not well suited to generate heat. This is because generating heat requires large amounts of energy, and to use PV electrical power for this is inefficient. For the causes of heating water and cooking, solar hot water heating systems should be used instead (Boxwell, 2010).

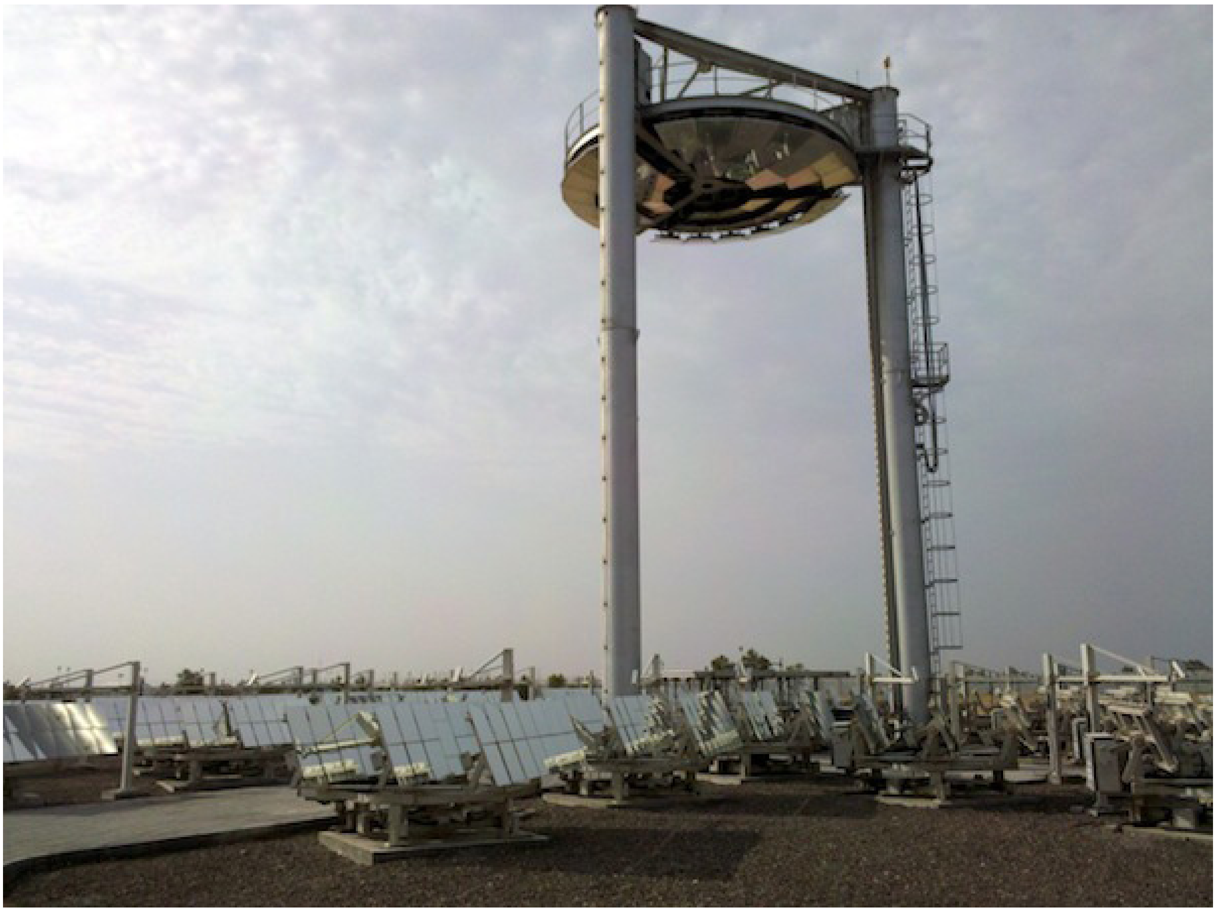


Figure 3.20: Beam-Down Solar Thermal Concentrator, by Hurst (2012)

3.3.3 Smart building design - energy and water consumption

The power generated from the city´s solar panels will be significantly less than the energy received from conventional hydrocarbon technologies. To compensate for this, the city aims to reduce its energy consumption by 70 % compared to the usage in other cities in Abu Dhabi (Nader, 2009).

According to Wheeler (2013) the main users of energy and materials in the world are buildings. In Norway buildings account for approximately 38 % of the used energy (Thue, 2003), and buildings in the US account for 40 % of the country´s used energy (Wheeler, 2013). This shows that buildings in developed countries consume a lot of energy, and that a lot of energy can be saved by smart design. This can again have a positive effect on CO_2 emissions.

Passive houses are buildings that have made measures to make them more energy and water efficient. Designing passive houses is usually done by insulating the building shell with plastic coatings and isolating materials. Windows, doors and other openings are also made leak proof. Light colored roof materials, vegetated roofs, and shading can also be used to limit the heat absorbed through the roof. Using flows of rising hot air and sinking cold air, can also be actively used to distribute air within the building. In addition, energy efficient systems for heating, ventilation and air-conditioning are used (Wheeler, 2013).

However, passive houses are often so efficient that natural airflows from the outside are almost non-existent. This can again have a negative effect on indoor climate, that can become unhealthy for the people living or working in the buildings (Braungart & McDonough, 2009). There are several toxins and chemicals released in a house from materials or elements residing in a building. Some of the toxins come from plastic coatings, paint, dry cleaning, carpets, detergents, moth crystals, fireplaces, curtains etc. (Buyuksonmez, 2012). These pollutants are confined inside when the air circulation is limited, and the need for active ventilation systems in passive houses are therefore important (Wheeler, 2013). Due to this, Braungart and McDonough (2009) claim that buildings with natural airflows can be just as environmentally friendly as passive houses. Buildings with natural airflows are according to them just as efficient as the passive house. The need for air-conditioning is reduced by designing windows that can be opened. Night time cooling and removal of air toxins is managed by natural airflows from the outside. Larger windows allow the light to enter, and the need for artificial lighting is reduced. The indoor climate is in general more pleasurable for the people working there, and supports a more productive workforce (Braungart & McDonough, 2009). This shows that there are different opinions on how to build more sustainable. It also shows that reduced energy consumption can be managed in other ways than complete insulation, or that the elements can be combined.

In addition, it is important to use local traditions and historical techniques in the architectural design. Many local design methods can provide energy efficient solutions. Among them are capturing cooling breezes, letting warm air flow out the rooftops, and designing shaded courtyards. Arabic design is for instance famous for the usage of towers to capture cool air and releasing hot air. Shaded verandas have also been used to protect the indoor from the sun (Wheeler, 2013).

All the buildings in Masdar City will be designed as passive and intelligent buildings, which is planned to reduce the energy demand significantly. All buildings will attempt to achieve the most efficient usage of resources. Local Arabic traditions are used to design the master plan, and the buildings will have high individual specifications. The hot climate requires a lot of inside cooling, and reduced heat radiation from the streets will save both energy and costs. Buildings and other elements are therefore designed to provide shade in the streets, at the exterior walls, and the roofs.

The PV panels on the rooftops will shield the buildings from the sun, and prevent heating of interior rooms from the ceiling. The streets are planned to be as narrow as 6 meters in some places, which will keep them shaded large parts of the day. Other design specifications are verandas that create shade in front of the windows, and creation of shaded courtyards underneath the buildings (Nader, 2009). The buildings are also planned to be constructed with sustainably harvested timber, 100% recycled steel, sand from the desert, 90% recycled aluminum, and low-carbon concrete (Masdar Institute, 2015). In addition, high-tech monitoring and control systems will be used to regulate the energy usage within the buildings (Nader, 2009). This system is called an Anticipated Building Management system (BMS), and it does for instance set the cooling temperature to a constant of 24 degrees (Günel, 2014).

The most common green building rating systems for passive houses are the British BREEAM (Building Research Establishment Environmental Assessment Method), and the American LEED (Leadership in Energy and Environmental Design) Green Building Rating system. Both systems have been developed to establish green building guidelines. LEED rates new buildings after how sustainable the site has been developed, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, and innovation in the design (Wheeler, 2013). LEED Platinum is the highest possible rating.

The Abu Dhabi Urban Planning Council (Estidama) developed their own rating system in 2010. This system is called the Pearl Rating System (PRS). The PRS aims to balance environmental, economic, cultural and social aspects, called the four pillars of sustainability. The program is tailor-made for the climate in the Middle East, and it states that all buildings must follow a three-part process to create more carbon efficient buildings. These parts are design, construction and post occupancy evaluation (POE). This means that there will be brought attention to all areas of the construction process.
The system also provides design guidance and detailed requirements for measuring a building´s performance. There are seven categories in the program and each new development is measured and rated according to their performance within each category. The seven categories are; Integrated Development Process, Natural Systems, Livable Buildings, Precious Water, Resourceful Energy, Stewarding Materials and Innovating Practice (Urban Planning Council, 2010). Five Pearls is the highest possible rating.

The buildings in Masdar City are planned to be rated after the more traditional rating systems, and the new Pearl Rating system. The energy and water consumption in each apartment and business will be recorded by the Anticipated Building Management system (BMS). The gathered information will be analyzed and used in the post occupancy evaluation (POE), and as information for the Masdar City residents. The information is planned to be displayed in different city features that will keep the residents updated on their water and energy consumption. This is planned to increase awareness and create collective responsibility for reduced consumption.

3.4 Masdar City plans and urban sustainability theory – concluding remarks

Table 3.1 displays a conclusion of the correspondence between Masdar City plans and sustainable urban form theory. Masdar City plans for the urban form corresponds well with theory. The exceptions are the planned number of commuters, and the large distances to surrounding areas. The plans do also correspond well with theory within the categories of renewable energy and smart building design. The exception is within zero waste, sustainable materials and water. The plans for Masdar City do no correspond with theories on how to become a zero waste city. The city does however plan to recycle 100% of its waste, treat and recycle water, and use sustainable building materials.

Strategies to become a low carbon city	Masdar City goals
Sustainable city planning and urban form	
Equal focus on environment, equity and economy	1/1
Sustainable urban form	10.5/12
High density	Yes
Good public transportation system	Yes
Short travel distances	Yes
Limited sprawl	Yes
Short distances to surrounding areas	No
Easy navigation	Yes
Pedestrian/bicycle friendly	Yes
Mixed use	Yes
Low rise	Yes
Design for micro climate	Yes
Developed on suited land areas	Yes and no
Inclusion of natural elements	Yes
Circular city metabolism	
Zero waste, sustainable materials and water	4/7
100% resource recovery from waste	No
Zero landfill and incineration	No
100% recycling of waste	Yes
Extended producer and consumer responsibility	No
Behavior change and sustainable consumption	Yes
Treatment and recycling of water	Yes
Use sustainable and recycled materials	Yes
Renewable energy	3/3
Photovoltaic (PV) solar panels	Yes
Concentrating solar plant (CSP)	Yes
Windmills etc.	Yes
Smart building design - energy and water consumption	5/5
Energy efficient	Yes
Reduced water consumption	Yes
Monitoring and control systems	Yes
Using natural airflows	Yes
Features to increase awareness and decrease consumption	Yes

Table 3.1: A summary of Masdar City goals for low carbon city development (I. Moxnes)

4. Detailed study of Masdar City

Chapter four is a detailed study of Masdar City. The study is based on observations that were made when I visited the city, and city performance data from Masdar Initiative. Literature is used as a supplement to analyze the observations. The city´s focus on environment, equity and economy is part of the conclusion and the chapter therefore starts with describing the urban form.

4.1 City planning and sustainable urban form - management of land areas

4.1.1 Sustainable urban form

As mentioned in chapter 3 Masdar City is planned to be 6 km^2 when finished. Figure 4.3 displays the planned development, the finished area, the areas under construction, the IRENA headquarters, the solar panel facility, and where two of the parking areas are located. It also shows how the city currently looks like from above. In 2015, eight years after the construction started, only 1.8% of the development is finished (see figure 4.1). The residents are the students living in the campus apartments, about 100-200 people. Additionally, the people working in the city are commuting there on a daily basis. Some of the companies located in the city are Siemens, General Electric, IRENA, Schneider, Mitsubishi, Sunpower and Total (see figure 4.2)

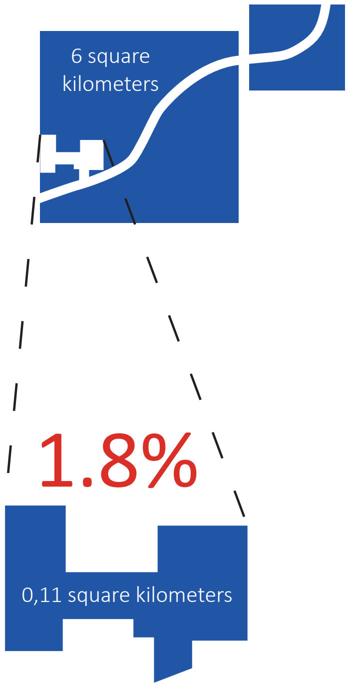


Figure 4.1: Built area (I. Moxnes)

With the city´s current size of approximately 13 hectares, Masdar City cannot be titled a city at the moment. It is rather a small cluster of buildings that perhaps can be compared with smaller parts of urban areas. The density in Masdar City does, as seen in figure 4.4, vary with the amount of included land areas. The density is between 20 and 40 people per hectare if only the area that immediately surrounds the buildings is included. The density is, on the other hand, between 7 and 15 people per hectare if the areas for parking and transportation are included. Together with the fact that none of the people working in the city are living there, the density can be seen as low at the moment. Furthermore, there were not many people in the city during the days of observation, and the streets and courtyards were mostly empty.

Masdar City can neither claim to be the first carbon neutral establishment in the world with its current size. There are in fact several other such projects, and Beddington Zero Energy Development in England is one of them (Girardet, 2015). The remarkable about Masdar City is the size of the planned development, which is not realized as of today. With the current speed of development, 1.8% in eight years, it might be questioned if the residing 98.2% will be finished in the next 15 years (which is the current goal). The two parking areas, as seen in figure 4.3, are constructed in the future green corridor and light rail area. They can be temporary, but combined with the slow development rate, it does raise questions concerning the reality of future development. The parking areas have roof structures that are built to shield the cars from the sun, and temporary structures do have a tendency to reside.

Figure 4.2: City companies (I. Moxnes)

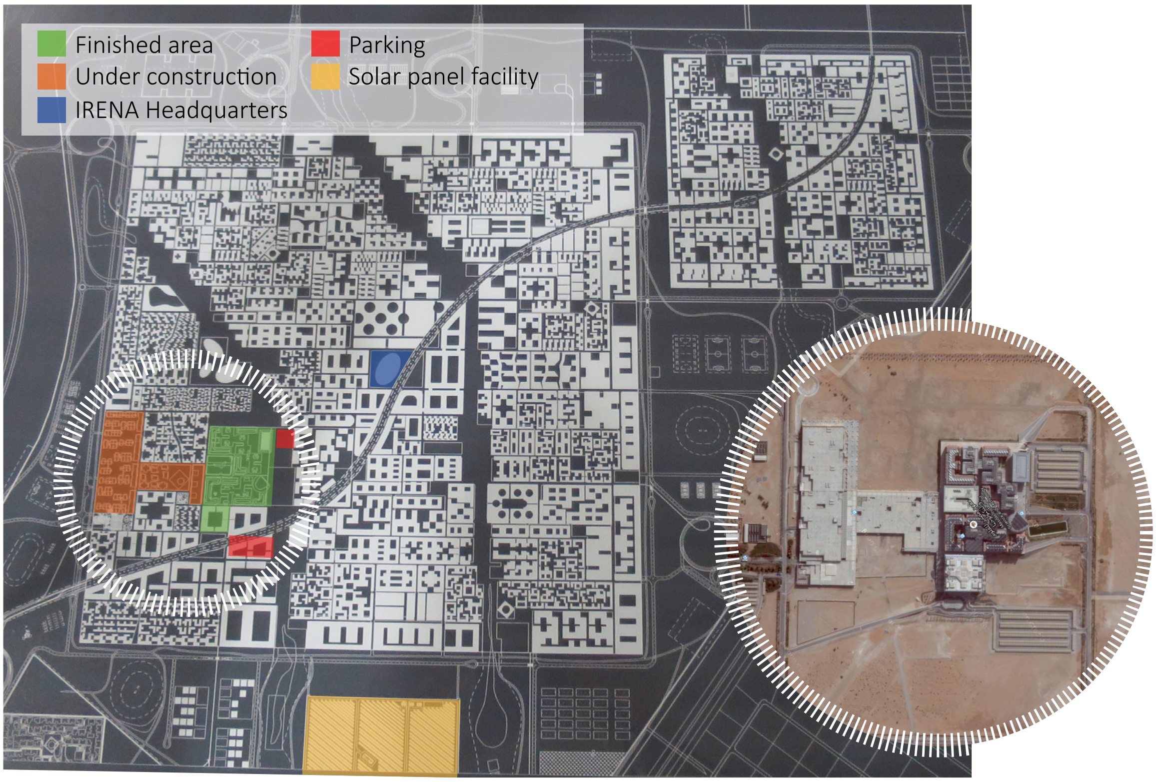


Figure 4.3: Plan for Masdar City displaying finished and developing areas (I. Moxnes)

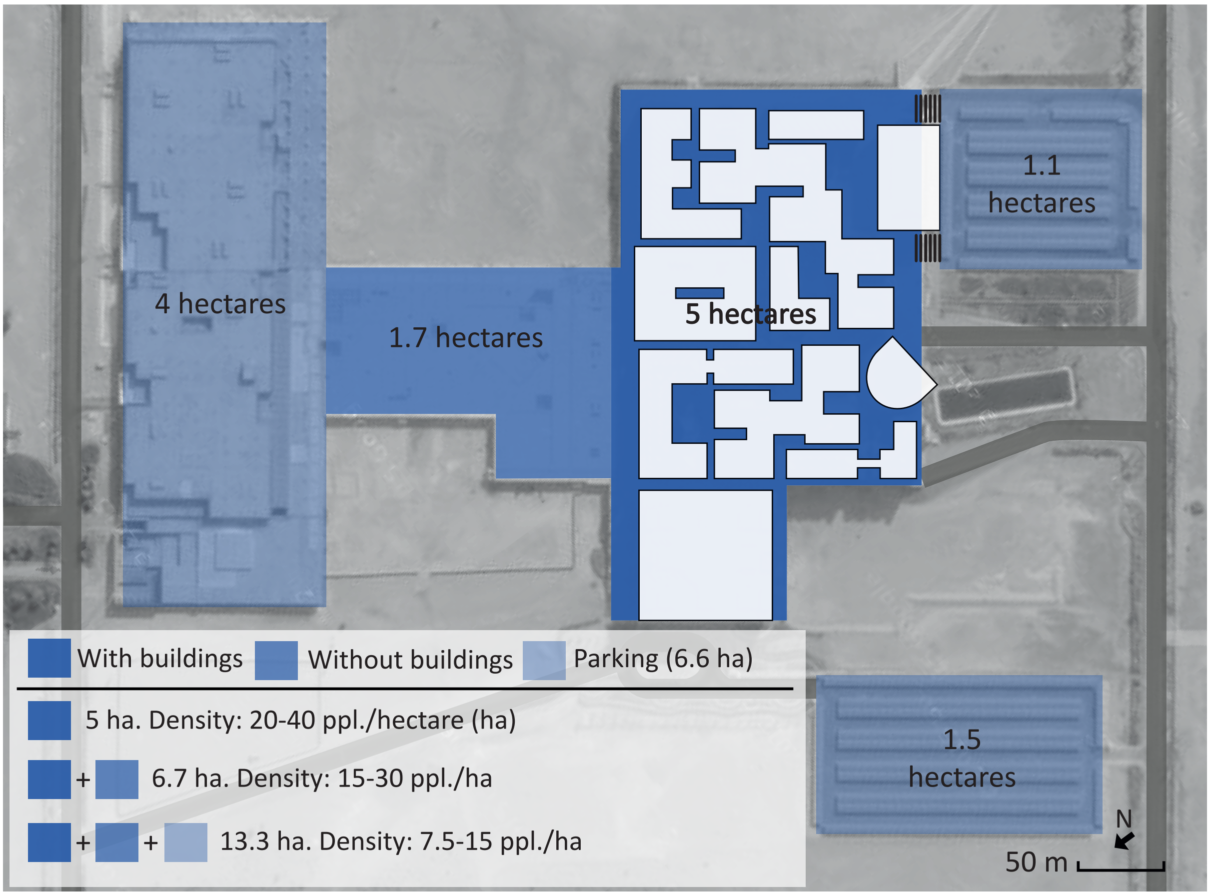


Figure 4.4: Area sizes and population density (I. Moxnes)

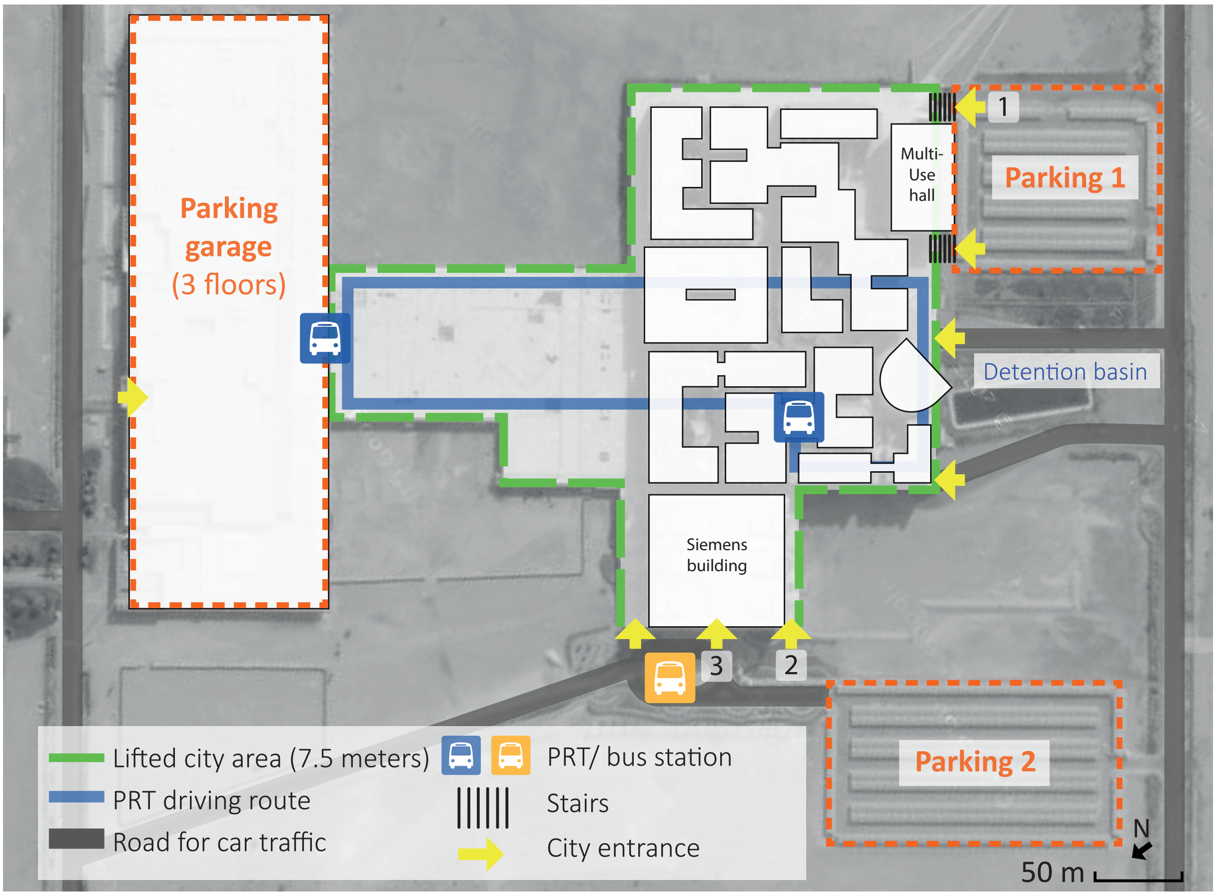


Figure 4.5: Traffic/transportation map (I. Moxnes)

Figure 4.5 displays a traffic/transportation map. The map shows the current city area, which has a clear border because of the 7.5 meter high pillars the city is standing on. The rest of the city will be built on ground level, and city entrances are displayed in the map. One of the entrances is through the Siemens building, with stairs and places for relaxation underneath the building. The city can be entered by stairs with the multi-use hall, and the city edge can be considered as a barrier to the surrounding environment. Figure 4.6 displays the city entrance with the multi-use hall, the city entrance next to the Siemens building, and the entrance underneath the Siemens building. The pictures in figure 4.6 are marked with number 1, 2, and 3 in figure 4.5. It is clear that the original concept of building the whole city on pillars with transportation underneath has been canceled.

Figure 4.6: City entrances. From the left: Number 1, 2 and 3 in figure 4.5 (I. Moxnes)

Figure 4.5 also displays the two roads located in the southeast part of the city. Even though the city is supposed to be car free, cars were observed at several times in the city center. There were some electrical cars, but also cars with internal combustion engines. These vehicles delivered goods and dropped off people, and the city´s goal of being car free is already undermined.

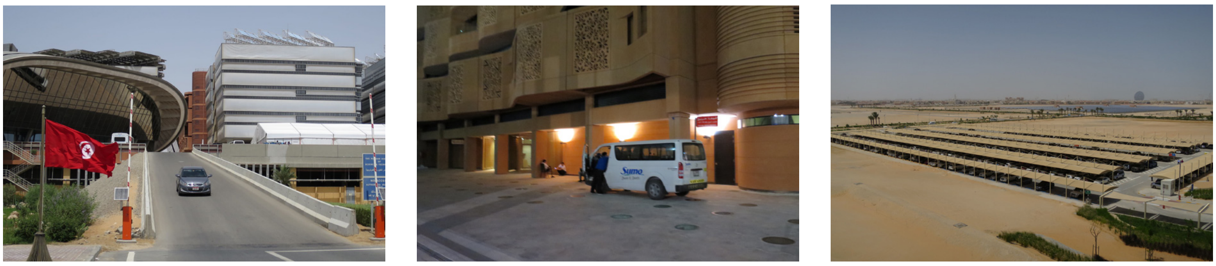


Figure 4.7: Cars observed in Masdar City and parking area 2 in figure 4.5 (I. Moxnes)

Figure 4.7 shows some of the observed internal combustion cars, and parking area two with the metal roofs shielding the cars from the sun (marked in figure 4.5). The future development on ground level is planned to allow electrical cars into the city. Nonetheless, if cars with combustion engines are already allowed it might be questioned if this is realistic. It also proves that it is difficult to sustain a project were cars are completely excluded. Even though the thought is good, it is hard to maintain in real life situations. The presence of cars was however limited, and the streets felt safe and relaxed.

There are three different parking areas (see figure 4.5), and cars are basically surrounding the city. The marked parking garage in figure 4.5 has a footprint of 4 hectares, and with three floors this equals 12 hectares for parking purposes. The ground areas intended for parking are 130% times larger than the area with buildings. The ratio is 290% if the three floors in the parking garage are included.

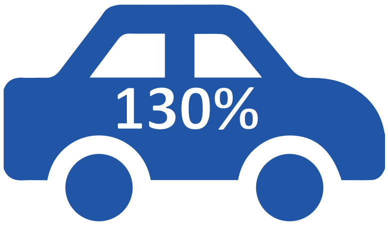


Figure 4.8: Ground area for parking / area with buildings (I. Moxnes)

The city is small, and even though most cars are parked outside, it can be questioned if the air is any cleaner inside the city borders. According to Foreman (2007) the government allows the residents one car in each household. The car is supposed to be parked in the parking areas, and will only be used for driving outside Masdar City. Nevertheless, this can be seen to have little influence on carbon emissions from car traffic at the moment. Cultural activities etc. are located outside the city, and residents have to travel by car to attend such activities. Two buses drive to Masdar City from the city center in Abu Dhabi, one each half an hour (Abu Dhabi Region Bus Services, 2012). Options for public transportation are limited, and transportation in Abu Dhabi is in general mostly reliant upon private cars and taxies (Department Of Transportation, 2013). Transportation to the city by bicycle is both unsafe and impossible due to the large highways leading to and from the area. The large parking areas, limited public transit options, unsafe bicycle travel, and large distances support the fact that Masdar City is most commonly reached by car.

Figure 4.5 also shows the two PRT stations. One of them is in the parking garage, and the other is inside Masdar Institute. According to working personnel there is one more station planned, and after construction the system is considered to be finished. The PRT system is only open between 8.30 AM and 4.30 PM due to the location inside Masdar Institute. The availability is in other words limited to opening hours, and cannot be used in the evenings and the night.

The PRT vehicles drive in 40 km/h, and the journey is over in a couple of minutes. The current PRT system has two one-way lanes, and the two stations have 5 berths each. The PRT journey can be described as both fun and safe, but the system felt more like an exhibition than an actual transportation system. The system is also high maintenance, and even though it is driverless, staff is needed at the stations to look after the vehicles. When they are charging, other vehicles need to be chosen. The PRT system is basically a mode of transportation to and from the parking garage, and not for transportation within the city.

Figure 4.9: PRT vehicle and its driving-lanes (I. Moxnes)

None of the FRT vehicles were observed, nor any stations for loading and unloading goods and waste. Combined with the fact that cars were driving in to the city to deliver goods, it can be questioned if the FRT system is operational at the moment. Figure 4.9 shows the PRT vehicles and the driving-lane underneath the city. Openings in the wall allows daylight to enter the transportation system.

Walking is the only mode of transportation within city borders and the walking distance from the Siemens building to the other side of the city is 308 meters. This means that the distances in the city are in general short. Together with the limited amount of cars in the streets it makes the city pedestrian and bicycle friendly. The streets are shared between bicyclists and pedestrians, but there were no bicycles nor bicycle racks observed in the city. This might however have something to do with the warm climate. Elevators are hidden away to promote the usage of stairs. This can be good to promote walkability, but it is also unpractical for people that need the elevators. The area should be designed so that everyone can use it, with one solution that works for everyone. Together with the stairs entering the city, it makes the area unsuited for people with a handicap or mothers with strollers. Hence the area is not universally designed.

Figure 4.10: The Knowledge center (I. Moxnes)

Figure 4.11: Wind tower (I. Moxnes)

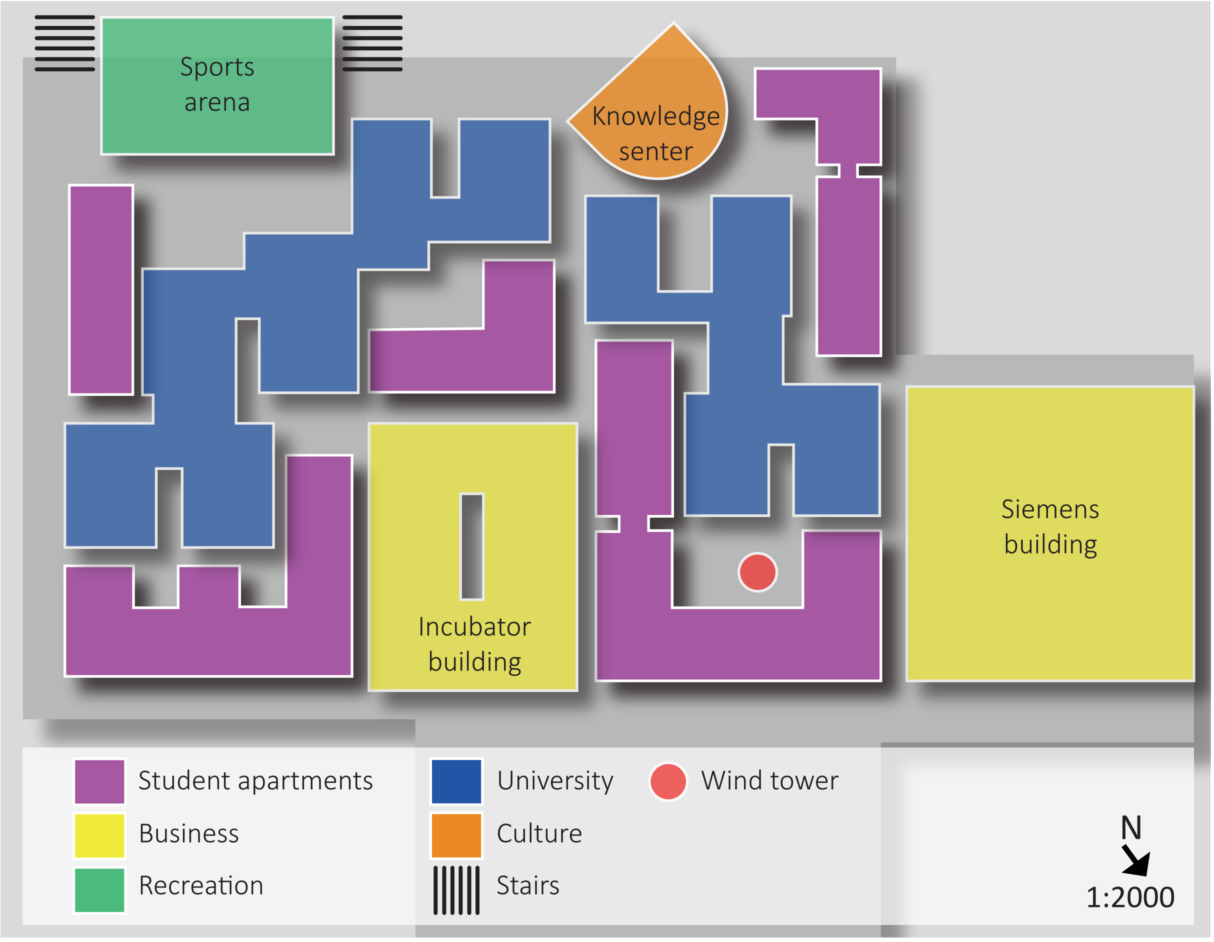


Figure 4.12: Function map (I. Moxnes)

The city is, as originally planned, low rise, with all buildings at approximately four stories. Figure 4.12 shows the different building functions in the city. The city contains 13 buildings. Five buildings with student apartments, five connected buildings (marked as two buildings) are for university purposes, and two buildings are for businesses. All of the buildings have different architectural expressions that make the city image exciting and non-homogeneous. The knowledge center, the multi-use hall and the wind tower can be seen as landmarks in the city (see figure 4.10 and 4.11). Though Masdar City has characteristic buildings that can be seen as landmarks, these are not tall enough to be spotted from other parts of the city. Inclusion of some taller structures might therefore have increased the sense of orientation. Then again, a landmark does not have to be tall to be important and effective.

There are no street signs, but information screens are located several places in the city. There are many passages and corridors located underneath the buildings that make the city less orderly. The sense of direction was therefore sometimes disturbed, and the city can only be described as connected to a certain degree. Figure 4.13 shows some of the areas underneath the buildings that provide the city with shaded areas to reside.

Figure 4.13: Areas underneath the buildings, some with benches (I. Moxnes)

The city is, as seen in figure 4.12, a small-scale mixed-use area. Cafeterias and small stores are located in some of the buildings at ground level. The buildings are also placed to form intimate courtyards that present the opportunity for relaxation in semi-public environments. Figure 4.14 and 4.15 display the courtyard inside the Incubator building and one of the other intimate courtyards. All of the courtyards are decorated with greenery and several concrete benches. The usage of concrete benches was chosen because the material is supposed to stay cool in the warm environment, but in 43 degrees Celsius they are still warm to sit on. The multi-use hall provides shade to a large outside area that can be used for dining (see figure 4.16).

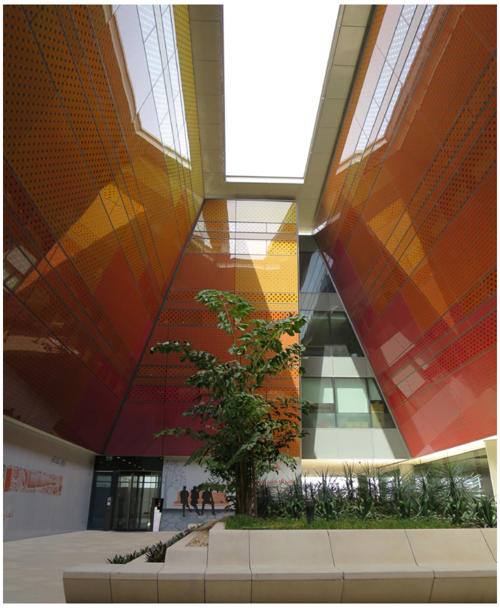


Figure 4.14: Courtyard inside the Incubator building (I. Moxnes)

Figure 4.15: Small courtyard (I. Moxnes)

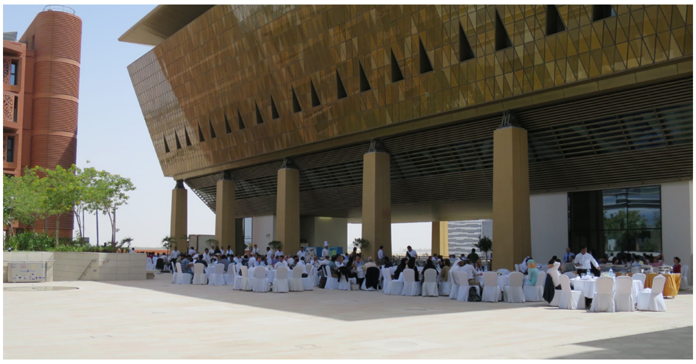


Figure 4.16: Dining in front of the multi-use hall (I. Moxnes)

In order to establish a good micro climate it is according to Jain (2009, p. 52) important to avoid large open spaces that can collect warm air and are ideal for sandstorms. The public spaces should be shaded, and decorated with vegetation and water elements that help cool the air. Shapeless pavement should be avoided because the hot surfaces will heat the air, and the building surfaces should be of light colors. The city footprint is illustrated in figure 4.18. The map shows that the streets and areas at ground level are more spacious than if seen from above. The many passages and public spaces underneath the buildings (as displayed in figure 4.13) create areas for relaxation that are completely sheltered from the sun.

Figure 4.17 Water elements and pavement in Masdar City (I. Moxnes)

Figure 4.18: Map displaying building footprint and courtyards with greenery and water (I. Moxnes)

The map also displays the courtyards decorated with greenery and water elements, and that the streets are mostly made up of hard elements. The pavement in the city is, as seen in figure 4.17, made of tiles in light colors. The figure also displays some of the water elements in the city. The courtyards are from 140 m^2 to 800 m^2 large, and with greenery in between the benches they become small semi-public areas to relax. As seen in figure 4.19 some of the streets are as narrow as six meters, making them shaded at all times. Whilst other streets are wider and sunny, as seen in figure 4.20 and 4.21. Many of the elements are, as described, according to Jain´s requirements for establishing a good micro climate. The park areas in the original plan are however not developed yet, and the courtyards are therefore the only places including natural elements at this moment. They are also the only places promoting activity. As seen in figure 4.20 and 4.21 the streets are mostly empty, with no elements for relaxation or promotion of activity.

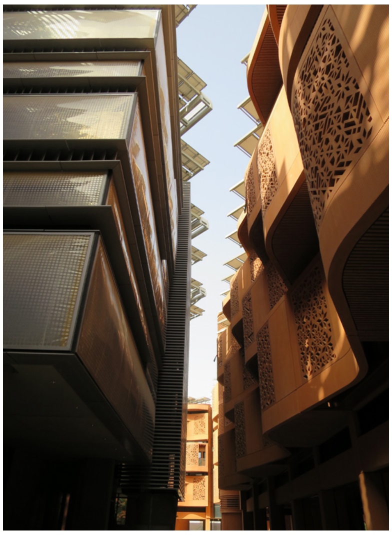


Figure 4.19: Narrow street (I. Moxnes)

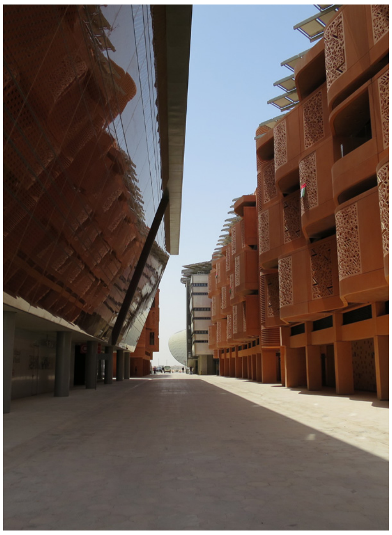


Figure 4.20: Wide street (I. Moxnes)

Figure 4.21: Wide and sunny street (I. Moxnes)

Figure 4.22: Masdar City seen from south-west. From the left; The Siemens building, student apartments,

Figure 4.22 displays the finished city area from the south-west. From the left; The Siemens building, the student apartments, the Knowledge center, Masdar Institute, and the multi-use hall.

The whole city is as mentioned designed to capture the outside wind and sustain natural breezes to cool the streets. The area underneath the Siemens building functioned as a wind tunnel that made the plaza underneath cooler than other areas in the city. Figure 4.23 shows the flowing air through the Siemens building. The building is designed to let hot air flow up through internal shafts, and allow cool air to enter from below. The shafts also provide light to the atrium underneath.

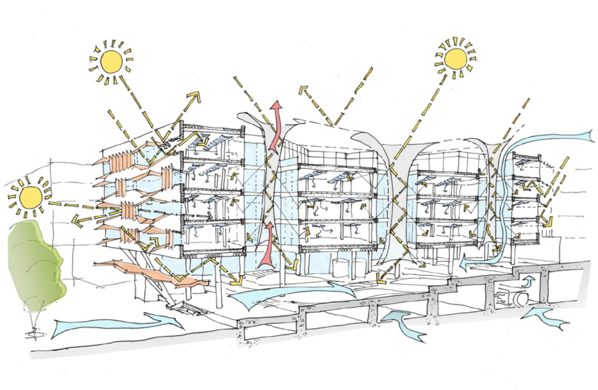


Figure 4.23: Sketch of the Siemens building showing natural airflows (Arch Daily, 2014)

Another element that is designed to achieve natural ventilation in the city is the wind tower located in the largest courtyard. The tower is a traditional architectural feature that has been used in older Arabic city planning. It is a 45 meter high structure that catches and directs winds down to the courtyard. Sensors and louvers at the top of the tower are used to capture winds, and water vapor is used to cool the air (Masdar, 2015). This is supposed to cool the streets, which again will cool the buildings, and reduce the energy consumption (Gunther, 2011).


the Knowledge center, Masdar Institute, and the Multi-Use Hall (I. Moxnes)

Nevertheless, the street temperature was equally warm as in other courtyards. One explanation might be that the wind arrives from outside the city, and since this wind is hot, the function diminishes. Another is that the downward movement energy of the cooled wind is low and can easily be balanced out by external wind causing an upward flow in the tower. The function is therefore highly dependent on the weather. As seen in figure 4.24 wooden gates for wind shielding were located in the courtyard entrances, but these were not used during the visit.

The courtyard with the wind tower is noisy due to the heating pumps in the Masdar Institute building. The noise level was measured to be 62 decibels, and after some time it became tiresome to rest there due to the constant noise pollution. The usage of heating pumps might therefore disturb an otherwise quiet environment. However, other parts of the city are more quiet and present an opportunity for relaxation in surroundings of 40-50 decibels.

Table 4.1 on the next page present a summary of the elements that are present in the urban form in Masdar City. The table displays what elements that are for or against a positive or negative conclusion in the different minor categories. Some of the conclusions have a clear yes and no answer, whilst others include a more detailed description. Some are also answered with both yes and no because the negative and positive sides are considered equal.


Figure 4.24: Wooden gates to shield the courtyard from outside winds (I. Moxnes)

Sustainable urban form – Masdar city reality 2015			
Goals	**For**	**Against**	**Conclusion**
Does the city have high density?	• Population density is Between 7 and 40 people per hectare	• There are no apartments for people working in the city	No
Is there a good public transportation system?	• Transportation with PRT from city to the parking garage	• Limited availability • High maintenance vehicles • Only transportation to/from the city • No transportation within the city	No
Are the travel distances short?	• Only 300 meters from one side of the city to the other		Yes
Is there limited or no sprawl?	• The city is being built within its original boundaries	• The city is not finished	Yes, at the moment
Are the distances to surrounding areas short?	• 15 minutes' drive to the airport - short taxi drive for foreign commuters coming from the airport	• Not possible to walk anywhere outside the city borders • 30 minutes' drive to Abu Dhabi city center • Limited access to public transportation	No
Is it easy to navigate in the city?	• Some landmarks • Distinctive and different building architecture • Maps for navigation several places	• The many open areas underneath the buildings disturb the sense of direction • No street signs • No tall landmarks	To some extent
Are the streets pedestrian and bicycle friendly?	• Short walking distances • Few cars • Hidden elevators	• Occasional cars in the streets • Usage of stairs to enter the city (not universally designed) • The city edge is a barrier	Yes, but not universally designed
Is the area planned for mixed use?	• Grocery stores, cafeterias and cafés in the center • Areas for housing, business and recreation are mixed together	• The residential buildings are only for students • There are limited cultural activities (no cinema, theatre etc.)	Yes and no
Is the city low rise?	• Four story buildings • All buildings have approximately the same height		Yes
Are the streets and courtyards planned for a good micro climate?	• Shaded streets and courtyards with benches for seating • Elements to capture and cool the wind • Greenery and water • Areas underneath the buildings with sofas etc.	• Some streets were without greenery, benches and elements to promote activity • Some places were noisy	Yes
Is the city developed on suited land areas?	• Earlier brownfield • Desert landscape	• Difficult ground with water pockets	Yes and no
Are natural elements included?	• Greenery and water elements in courtyards	• No parks • Large concrete surfaces	No

Table 4.1: Pros and cons for achieved goals within urban form (I. Moxnes)

4.2 City metabolism – management of resources

4.2.1 Zero waste, sustainable materials and water

Figure 4.25: Waste management in Masdar City (Masdar Initiative, 2014)

Figure 4.25 shows current waste management in Masdar City (Masdar Initiative, 2014). 346 tons of operational waste was produced from consumption in the buildings in 2014. The recycled elements are cans, plastic, and paper, which equals 8.5% of the total waste products. Figure 4.26 shows an ordinary recycling station located in the streets of Masdar City. The on-site compost bin can manage up to one ton of organic wastes, and 1% of total wastes were composted in 2014. The rest of the waste was disposed at a landfill. Management of construction waste is however more impressing, where 60% of all wastes are recycled. 100% of steel, concrete and wood is recycled, and some paper/cardboard and plastic is recycled as well (Masdar Initiative, 2014, pp. 104-105). Nevertheless, disposing 90.5% of the operational waste, and 40% of the construction waste at a landfill is not according to the goals of recycling 100% of all waste. Merely recycling cans, plastic, and paper from the operational waste seems to be a modest effort. Additionally, other materials than steel, wood and concrete can be recycled at a high rate. Some of them are glass and other metals.

Figure 4.26: Recycling station for paper, plastic, cans and trash in Masdar City (I. Moxnes)

Incineration of waste is not operational in Masdar City as of 2014, which can be considered as good if the city plans to become better at recycling. It is nonetheless, as described in chapter three, worse with landfill disposal than incineration. Unfortunately, the amount of construction waste was not possible to retrieve, and a combined percentage for the amount of recycled waste was therefore not possible to obtain. The overall impression is however that Masdar City does handle a lot of the waste in an environmentally friendly way, but at this point not enough to be named a zero waste city. Even if 100% recycling is not possible, according to obtained data, more of the produced wastes in Masdar City can be recycled. Especially within operational wastes, but also within wastes produced from construction.

Masdar City has used several sustainable building materials in the constructed buildings. All timber is sustainably harvested, whilst recycled scrap is used to make steel reinforcing bars. Almost all the aluminum used for sheeting, windows and doorframes in Masdar City is 90% recycled. This means that the carbon footprint is over 80 % lower than if virgin aluminum was used (Masdar Initiative, 2015). This is because only 5% of the energy used to produce new aluminum is required to recycle it (Wikipedia, 2015a). Figure 4.27 shows the sustainably harvested timber used to construct the Knowledge center, and figure 4.28 shows the recycled aluminum used to cover the windows in the Masdar Institute building.

All the concrete used in the city is low-carbon concrete. This type of concrete has a lower environmental footprint because up to 60% of the Portland cement, which is very energy-intensive, has been replaced with a waste product of iron making (granulated blast-furnace slag) (Masdar Initiative, 2015). This means that a large percentage of the used resources in the city have been sustainably obtained. The used materials are, however, only to a small degree recovered from waste.

The on-site membrane bioreactor (MBR) sewage treatment plant has a peak capacity of 1500 m^3, and the products are treated water and bio solids (Pirani et al.,2011). Construction activities receive water from the MBR plant and most of the water is used to irrigate the landscape and suppress dust on construction roads. The dust suppression reduce air particulates and increase the air quality in local communities. In 2014 the city consumed 43.159 m^3 of water, and additionally 84.150 m^3 was used for construction. 21.276 m^3 of this water was sourced from the MBR plant (Masdar Initiative, 2014, pp. 101-102). This means that 17% of the consumed water in Masdar City and for construction activities was recycled in 2014, which means that 83% was retrieved from the distribution network.

Figure 4.27: The sustainably harvested timber in the Knowledge center (I. Moxnes)

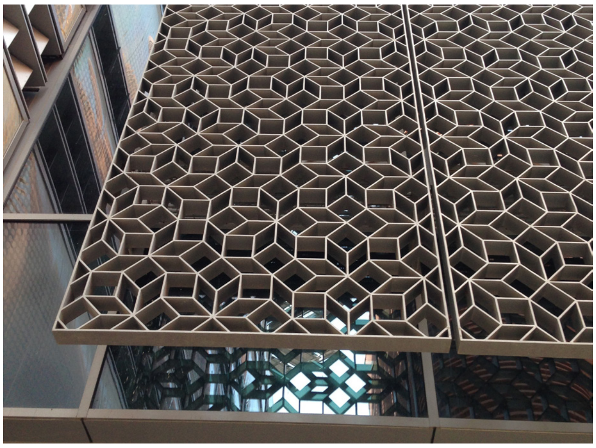


Figure 4.28: Recycled aluminum used to shield the windows in the Masdar Institute (I. Moxnes)

Table 4.2 shows a summary of the elements weighing for or against a positive or negative conclusion in the different minor categories within zero waste, sustainable materials and water production. Many of the minor groups have a negative conclusion because the goals were not fulfilled in the original plan nor in reality. The minor groups for sustainable materials and recycling of water does however have a positive conclusion.

Zero waste, sustainable materials and water production - Masdar City reality 2015			
Goals	For	Against	Conclusion
Does the city recover 100% of used resources from waste?	• Some resources are recovered from waste; recycled steel and aluminum used for construction • Some of the used glass is recycled	• More resources could have been recovered from waste	No, only some
Does the city use a zero landfill and incineration policy?		• 90.5% of operational and 40% of construction wastes are disposed at a landfill	No
Does the city recycle 100% of wastes?	• 60% of construction wastes are recycled • 100% of wood, steel and concrete is recycled • Cans, plastic and paper are recycled • Some organic waste is composted and reused	• Only 8.5% of total operational waste is diverted from landfill • Other materials can also be recycled	No, but 60% of construction wastes
Does the city extend producer and consumer responsibility?		• Increased prices on goods with a high environmental impact, like gasoline, could have been implemented	No
Does the city promote behavior change and sustainable consumption?	• Education is planned to make consumers recycle more • Research and knowledge provides the opportunity to change behavior	• There are no places for local production of goods and food • Consumption of goods is the same as in other places • Taxes and fees can be used to regulate and influence the amount of consumed goods	No
Does the city treat and recycle used water?	• On-site waste water treatment plant • 50% of used water is recycled and reused • Recycled water is used to irrigate the landscape	• Fresh water is produced from sea water - energy intensive and without renewable energy source	Yes, but the water is not sustainably produced
Does the city use sustainable materials?	• Sustainably harvested timber and low-carbon concrete is used		Yes

Table 4.2: Pros and cons for achieved goals within waste, material and water management (I. Moxnes)

4.2.2 Renewable energy

The photovoltaic (PV) panels on the rooftops are directed towards the south to optimize the suns capacity. As seen in figure 4.29 they also provide shade in the streets because they are placed outside the roof in some places.

Figure 4.31 shows that the solar panels are full of sand and dirt and do not seem to be letting any sun through. Figure 4.30 displays the dirt on top of the buildings where the solar panels are located. The picture is shown because the amount of dirt was more easily displayed in the image with the red concrete as background. When observing the solar panels later that week they were still not clean and it can be questioned if they receive proper maintenance.

According to solar panel expert, Afshin Afshari (Bollet & Demarle, 2015), they have to be cleaned regularly to function optimally in the Arab climate. As seen in figure 4.32, the PV panels in the large on-ground facility were clean and seemed to be maintained properly. It is easier to see how dirty the solar panels in figure 4.31 are when compared to figure 4.32.

Al-Hasan (1998) presents several researchers work on the effect of sand dust on PV panels. According to Sayigh (1978) the collected energy can be reduced by 30% after 25 days without cleaning. Sayigh, Charchafchi and Al-Habali (1979) claim that the generated power is reduced with “2%, 14% and 30% after one, 13 and 32 days, respectively without cleaning”. Wakim (1981) discovered a power reduction of 17% in PV panels after six days due to gathered sand dust in Kuwait. Combined with the more recent statement from Afshin Afshari this means that the PV panels on the rooftops produce up to 30% less energy than the optimal production capacity. Further this means that they only produce 1050MWh of electricity a year, perhaps less if the number of days without maintenance is higher.

Figure 4.29: Solar panels placed outside of the roof edge (I. Moxnes)

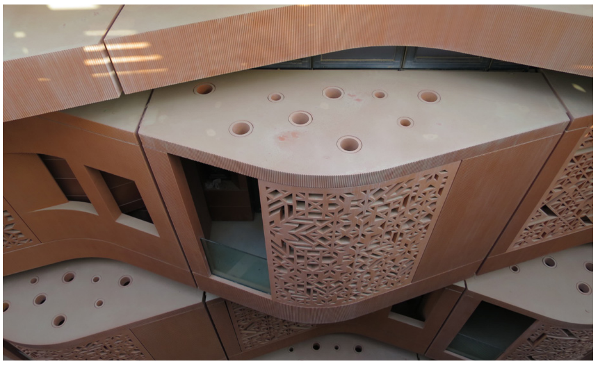
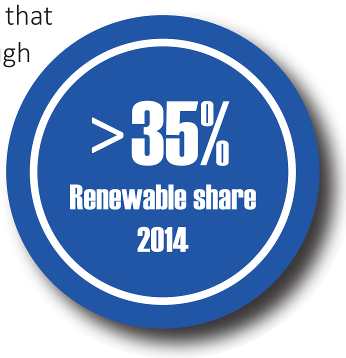


Figure 4.30: Dirt and sand on the roof of the residential buildings (I. Moxnes)

Figure 4.31: Dirt and sand on the solar panels on top of the residential buildings (I. Moxnes)

Figure 4.32: Clean solar panels in the 10MW facility on the ground (I. Moxnes)

In 2014 Masdar City´s total energy consumption was 53.700MWh, where 38.300MWh was direct building consumption (70% of total consumption). 15.400MWh was indirect consumption from chillers, the beam down solar plant, and the Membrane Bioreactor. This means that the produced energy from the PV solar panels (totally 19.000MWh) is not enough to sustain the city´s consumption, and energy from the national grid has to be used (Masdar Initiative, 2014, p. 99). Less than 35% of the used energy is produced from the PV panels. This again means that energy produced from natural gas, which is the source of the energy in the national grid (Pirani et al., 2011), is used to provide the city with enough energy. The city´s energy consumption is therefore not completely clean. Additionally, the fossil fuels used for transportation will decrease the renewable share further, hence less than 35%.



As mentioned earlier it is still not beneficial to choose PV power over power from hydrocarbon fuels. If the maintenance cost for cleaning the solar panels regularly is higher than using energy from the national grid, this might be the reason for the lacking maintenance. Despite the reason, the solar panels on the rooftops in Masdar City do not function optimally due to lacking maintenance. It shows that the sandy climate in the Emirates provide challenges for solar energy that might not exist to a similar degree in Norway.

Table 4.3 shows a summary of the elements weighing for and against a positive or negative conclusion in each minor group within renewable energy. It concludes that Masdar City uses both natural gas and energy from the PV panels, that the energy produced from the Beam-Down Solar Thermal Concentrator is limited, and that the city does not yet use windmills for energy production.

Renewable energy - Masdar City reality 2015			
Goals	For	Against	Conclusion
Does the city use PV panels for energy production?	• 10MW solar panel facility • Solar panels on the rooftops of Masdar Institute, the residential buildings, the Knowledge center and IRENA Headquarters	• Only less than 35% of the used energy is renewable • The city has to use energy from the national grid to supply enough energy (this energy is produced with natural gas) • The solar panels on the rooftops are not properly maintained	Yes and no
Does the city use a concentrating solar plant for energy production?	• 100 kW Beam-Down Solar Thermal Concentrator	• Produce limited amounts of energy • For research purposes	Yes, but in a limited extent
Does the city use windmills?		• No, the planned windmills are not constructed yet	No

Table 4.3: Pros and cons for achieved goals within renewable energy production (I. Moxnes)

4.2.3 Smart building design - energy and water consumption

The Siemens building (seen in figure 4.33) is classified as a LEED Platinum Building and have received 3 pearls in the Estidama rating system. This means that the building is very energy and water efficient, and the building uses 63% less water and 65% less energy than the Abu Dhabi average. The inside is highly insulated and airtight, whilst the exterior walls are made of lightweight aluminum in different shapes. The exterior walls provide shade that minimizes solar heat from warming up the inside. At the same time it maximizes daylight (Masdar Initiative, 2015).

The incubator building is displayed in figure 4.34. It provides shade to the environment by angling the walls outward in the streets and inward in the courtyard (also displayed in figure 4.14 and 4.20). The building also minimizes the amount of sun that reaches the exterior walls by an average of 30%. In addition there are circular ceramic frit dots on the glass walls that prevent the suns heat from entering the building. At the same time they let the sunlight shine through. The dots are denser at the top of the building where there is more sunlight. Some of the windows can be manually opened and present the opportunity for natural ventilation (Masdar Initiative, 2015).

IRENA Headquarters is located away from the rest of the development (see figure 4.3). The building currently stands alone on an open field, and transportation by car is necessary to get there. The construction consists of three buildings that surround an atrium. The construction has seven stories and 32.000 m^2 of workspace. It is classified as an Estidama 4 pearl, and has 1.000 m^2 of PV panels on the roof. These panels supply the building with 10% of the buildings energy consumption. Sustainable timber, recycled aluminum and steel, and low-carbon concrete are some of the materials used in the building (Masdar Initiative, 2015).

Figure 4.33: The Siemens building (I. Moxnes)

Figure 4.34: The Incubator building (I. Moxnes)

Figure 4.35: IRENA Headquarters (I. Moxnes)

The Masdar Institute buildings are, as seen in figure 4.36, designed with small windows, making up less than 40% of the exterior wall surfaces. Vertical shadings are used to avoid direct sunlight from entering the buildings in the morning and afternoon, and horizontal shades are used to block the midday sun. The buildings are also highly insulated and airtight to prevent the hot air from accessing. The exterior walls are covered with air-filled ETFE (Ethylene tetrafluoroethylene) cushions that are supposed to limit the amount of hot air re-radiated to the streets. They are also supposed to send light to the streets (Masdar Initiative, 2015). However, the streets were equally warm between the Masdar Institute buildings and other buildings without the ETFE cushions. The ETFE cushions are neither relevant for Norwegian conditions.

The multi-use hall is displayed in figure 4.37. The building stands on poles, and there is an outdoor swimming pool underneath the building that was dry when observing. The pool is shaded due to its location underneath the building. The building consists of a gym, and a multi-use hall for sporting events and conferences (Masdar Initiative, 2015).

The student apartments are built with undulating glass-reinforced concrete, which give them the distinctive terracotta-color. Balconies are used to prevent direct sunlight from entering the apartments. Vents on the ground level and open louvers in the ceiling naturally ventilate large inside atrium's. The vents and louvers are closed when the weather is hot, and open during the night when the outside air is cooler (Masdar Initiative, 2015).

The knowledge center is built with sustainable wood (glued laminated timber) because the material provided a lower carbon footprint than steel. Zinc claddings cover the exterior roof of the building (Masdar Initiative, 2015). Zinc cladding is a metal formed under high pressure and temperature. The material is ideal as an insulating layer on the outside of a building (Language, 2011). The roof shades a large outdoor area, and at the same time it prevents sunlight from heating the inside (see figure 4.39) (Masdar Initiative, 2015).

Figure 4.36: Masdar Institute (I. Moxnes)

Figure 4.37: The multi-use hall (I. Moxnes)

Figure 4.38: The student apartments (I. Moxnes)

Figure 4.39: The Knowledge center (I. Moxnes)

This shows that the individual specifications for all of the buildings in Masdar City are high. It also displays that all the buildings have made measures to become as energy and water efficient as possible. The used building materials are varied, but they are all characterized by an attempt to use as sustainable materials as possible. Some of the buildings do also use the principles promoted by Braungart and McDonough by presenting windows that open and vents in the ceiling. However, not all of the buildings are rated after the green building rating systems mentioned in chapter three. Only the Siemens building and IRENA Headquarters are rated after the LEED and Estidama Pearl rating system, and only the environmental performances of these buildings are presented. Together with the earlier presented energy performance data, this might mean that the other buildings are not as energy efficient.

All recorded data from the city´s water and energy usage is, as mentioned in chapter three, gathered and analyzed at Masdar Institute. An incentive to improve the resident's awareness of consumption is an information screen that is placed in the middle of the campus area. Recently updated information on water and energy consumption is supposed to be displayed. Unfortunately the screen was, as seen in figure 4.40, not turned on during the days of observation.

The wind tower is also supposed to be an indicator on energy and water consumption. By glowing either blue or red in the evening it is supposed to show if the energy and water consumption goals are met. Blue means that the goals are met and red means that the city is using to much energy (Bollet & Demarle, 2015). However, the lights were not working, and instead of glowing red or blue the lights were simply yellow (as seen in figure 4.41).

Figure 4.40: The information screen that is supposed to display the city´s water and energy consumption. The screen is not on (I. Moxnes)

Figure 4.41: The wind tower at night. The tower is glowing yellow and is currently not an indicator on energy/water usage (I. Moxnes)

Table 4.4 shows a summary of the elements weighing for and against a positive or negative conclusion in each minor group within smart building design. It concludes that the buildings in Masdar City are designed to be energy efficient, and that they have monitoring and control systems installed that help reduce the electricity and water consumption. Some of the buildings do also use natural airflows for ventilation. The city does have features to promote reduced consumption, but they were not displaying the necessary information.

Smart building design – energy and water consumption - Masdar City reality 2015			
Goals	Positive	Negative	Conclusion
Are the buildings energy efficient?	• All the buildings are passive and intelligent buildings • All the buildings have high individual specifications	• 70% of the city´s total energy consumption is for the buildings	Yes
Do the buildings reduce water consumption?	• The Anticipated Building Management system (BMS) is used to reduce water consumption • Consumption is measured and registered • The Siemens building use 63% less water than the average in Abu Dhabi	• All the buildings have not been rated as a LEED Platinum building	Yes
Are monitoring and control systems used?	• The BMS system controls temperature and energy usage • Energy and water consumption is measured and registered		Yes
Are natural airflows used?	• The residential buildings, the Incubator building and the Siemens building use natural airflows for ventilation		Yes
Are there features to increase awareness and reduce consumption?	• The wind tower • The information screen	• Energy and water usage is not displayed in any of the features	No

Table 4.4: Pros and cons for achieved goals within smart building design (I. Moxnes)

4.3 Study of Masdar City, concluding remarks

Table 4.5 shows the conclusions in all the minor groups for the Masdar City goals and reality. The table shows that some of the elements are according to the original plan, and some are not. Fewer minor groups have a positive conclusion in the Masdar City reality than in the Masdar City goals. This shows that the city has, as of today, not been able to fully realize the original plans. Only half of the minor groups within urban form and renewable energy are fulfilled. Within zero waste, only two of seven goals are fulfilled. The only category receiving a nearly full score is the smart building design.

One of the reasons for the negative conclusions within urban form is that only a small part of the original plan has been developed, and the answers might be different if researched at a later time. Nevertheless, some measures do also have a negative conclusion because they are unsuccessful or only partly successful.

According to the perspectives of the economic, equity and environmental planner presented in chapter three, only the economic planner´s vision has so far been realized in Masdar City. Non of the communities have been developed, nor any of the urban parks. The businesses and market areas are however developed, and many firms promoting environmentally friendly solutions have resided in the city. The city has, as Jain described, become a center for commuting and economic activity. The fact that 37% of the city is planned for economic purposes also point towards economy being most important. The gathered data do therefore present it as unlikely that the city has an equal focus on equity, economy and the environment as of today.

Total emissions from Masdar City in 2014 were 29.1227 tons of CO_2. In chapter one, three emission scopes were defined in figure 1.1 and 1.2. Masdar City´s emissions in scope one were 1440 tons of CO_2 in 2014. 25,465 tons were emitted in scope 2, and 2242 tons of CO_2 in scope 3. The usage of PV solar panels reduce the emissions with 642 tons of CO_2 annually, and the emissions are reduced with 17% from 2013 (Masdar Initiative, 2014, p. 109). This means that the largest part of the city´s emissions are located in scope two, which have not been evaluated in this thesis. It also means that when 1440 tons are emitted within scope one, where many of the city´s goals are not met, the goals are unlikely met in the other scopes where the emissions are even higher.

Strategies to become a low carbon city	Masdar City goals	Masdar City reality 2015
Sustainable city planning and urban form		
Equal focus on environment, equity and economy	1/1	0/1
Sustainable urban form	10.5/12	5.5/12
High density	Yes	No
Good public transportation system	Yes	No
Short travel distances	Yes	Yes
Limited sprawl	Yes	Yes, at the moment
Short distances to surrounding areas	No	No
Easy navigation	Yes	To some extent
Pedestrian/bicycle friendly	Yes	Yes, but not universally designed
Mixed use	Yes	Yes and no
Low rise	Yes	Yes
Design for micro climate	Yes	Yes
Developed on suited land areas	Yes and no	Yes and no
Inclusion of natural elements	Yes	No
Circular city metabolism		
Zero waste, sustainable materials and water	4/7	2/7
100% resource recovery from waste	No	No, only some
Zero landfill and incineration	No	No
100% recycling of waste	Yes	No, but 60% of construction wastes
Extended producer and consumer responsibility	No	No
Behavior change and sustainable consumption	Yes	No
Treatment and recycling of water	Yes	Yes, but not sustainably produced
Use sustainable and recycled materials	Yes	Yes
Renewable energy	3/3	1.5/3
Photovoltaic (PV) solar panels	Yes	Yes and no
Concentrating solar plant (CSP)	Yes	Yes, but in a limited extent
Windmills etc.	Yes	No
Smart building design - energy and water consumption	5/5	4/5
Energy efficient	Yes	Yes
Reduced water consumption	Yes	Yes
Monitoring and control systems	Yes	Yes
Using natural airflows	Yes	Yes
Features to increase awareness and decrease consumption	Yes	No

Table 4.5: A summary of Masdar City goals and Masdar City reality to become a low carbon development (I. Moxnes)

5. Are the measures made in Masdar City relevant for low carbon urban development in Norway?

5.1 Introduction to Norway

Norway is, as seen in figure 3.2 in chapter three, located in the north. The country has a population of nearly 5.2 million people. The population growth is low, with only a 12% increase in the last ten years (SSB, 2015c). In 2014 80% of the population lived in urban areas (SSB, 2014a), and several of the smaller villages are threatened by depopulation.

The country is one of the wealthiest in the world, and a large part of the country´s income is based on oil and gas production. Norway was the 5th largest exporter of oil and gas in the world in 2008 (Bøeng, 2010). The country is democratic and socialistic, and the population does in an average pay about 33% of their income in taxes.

The Norwegian city culture is characterized by low-rise buildings, often single family dwellings and townhouses. As seen in table 5.1 the density in many cities is therefore low, and urban areas do in general sprawl. The density in the largest urban areas in Norway is between 4 and 18 people per hectare. Some cities, like Oslo and Bergen, do however have denser city centers with apartment buildings and block structures. Grünerløkka in Oslo does for instance have a density of 93 people per hectare, and Bergen city center has a density of 48 people per hectare. Figure 5.2 displays a map over Norway where the cities shown in table 5.1 are marked.

The Norwegian climate is characterized by cold winters, sometimes reaching temperatures as low as 30 degrees minus in the east and north. The summers are mild with temperatures around 20 to 25 degrees Celsius, with regional variations. The weather in the coastal areas in the west are characterized by rain and at times strong winds, whilst the winters in the east often have a lot of snow. The country does in general have large nature areas with forest landscapes, fjords, and a lot of fresh water lakes. One of these lakes is seen in figure 5.2, with the Norwegian Museum of Hydropower next to the lake.

As seen in figure 5.1, CO_2 emission in Norway makes up approximately 84% of all emissions, where 29.48 % is from oil and gas production. Norwegian emissions from energy production are only 4 % because the country uses mostly hydropower, as seen in figure 5.2, for electricity production. Electrical heating is the most common, and this results in low emissions from ordinary households (2.85 %) (Bøeng, 2010). Norwegian emissions are approximately the same as the average in Western Europe. The country´s energy consumption is however a lot higher than the average, but the usage of hydropower results in reduced emissions (Miljødirektoratet, 2014).

According to the Kyoto Protocol, Norwegian emissions are supposed to be reduced by 16% within 2020. The annual Norwegian emissions are, as of today, larger than the allocated quota. Additional measures are therefore necessary to meat the goals (Miljødirektoratet, 2015).

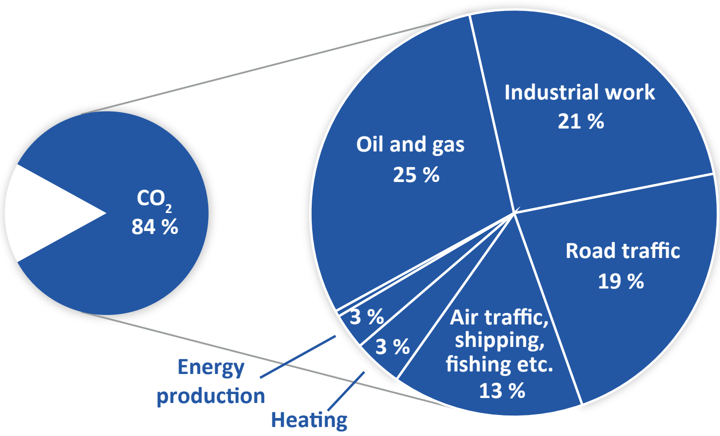


Figure 5.1: Norwegian carbon dioxide emissions (Bøeng, 2010)

Population and density in different Norwegian cities		
City / city area	Population	Density
Oslo	647,676	14
- Grünerløkka	43,961	93
Stavanger	130,429	18
- Stavanger Øst	4000	67
Bergen	272,520	5.9
- Bergen city center	818	48
Trondheim	183,960	5.7
Drammen	62,566	4.2
Tromsøya	36,088	15.8

Table 5.1: Population and density in different Norwegian cities (Wikipedia, 2014, 2015e, 2015g, 2015m, 2015o, 2015q, 2015s)

The Norwegian parliament aims to become carbon neutral within 2030, and intend to reduce emissions by introducing improved building regulations, increase the share of public transit, and buying carbon offsets in other countries (Bøeng, 2010; Wikipedia, 2013).

Since Masdar City has been unsuccessful in focusing equally on the environment, equity and economy, this category is concluded to be of limited relevancy for Norwegian development. It is not that the overall goal is irrelevant for Norway, but it has not been implemented in Masdar City, hence the negative conclusion. The category is therefore not further discussed in chapter 5, and the chapter starts with evaluating the relevancy of the urban form developed in Masdar City as of 2015.

Figure 5.2: Location map displaying Norwegian cities (I. Moxnes), and pictures showing a hydropower dam (Sandru, 2013) and the Norwegian Museum of Hydropower Industry (Urban Realm, 2012)

5.2 City planning and urban form – management of land areas

5.2.1 Sustainable urban form

As seen in table 4.5 only half of the goals to achieve a sustainable urban form has been realized in Masdar City as of 2015. When the measures are unsuccessful their relevancy for other developments naturally diminishes. Nevertheless, some of the unsuccessful measures might teach Norway something about how not to develop. All of the twelve minor groups within urban form are therefore discussed in this sub-chapter.

As a whole, the relevancy of developing a completely new city in Norway can be seen as limited. The population growth in Asia and the United Arab Emirates (UAE) is in general higher than the population growth in Norway. As mentioned in chapter three, the UAE has an exceptionally large amount of expatriates. This growth makes it necessary to develop new urban areas to make room for the increasing urban population. The low population growth in Norway, and the already low density, makes it more relevant to focus on urban renewal and infill development in already existing cities. However, the current size of Masdar is very small, and could just as well have been an infill project in an existing city. The positive urban form measures in Masdar City can therefore be seen as relevant for development in smaller urban areas within current cities. Due to this, the most frequently used Norwegian comparison cities in this sub-chapter are cities with a large population growth. These cities are in the need for urban renewal projects within their limits.

Increased density can, given the existing low density in many Norwegian urban areas, have great positive effects on reduced emissions. The current density in Masdar City is nevertheless, as described in chapter four, not very high when all developed areas are included in the calculation. This means that Masdar city is in terms of density not particularly relevant for Norwegian development at the moment.

In 2008 25% of Norway´s total usage of energy was due to transportation, and from 2000 to 2009 the usage of energy for transportation increased with 14 % (Bøeng, 2010). This shows that there is an increasing need for energy, and that the share of energy used for transportation is likely to increase in the coming years. Within transportation only 1.6% of the used energy is renewable (electrical), and trains, trams, metros and electrical cars are the main users (SSB, 2013c). Decreased energy usage and changed energy sources within the transportation sector can therefore be seen as necessary to decrease Norwegian emissions. The relevancy of establishing an efficient and demand pleasing public transit system can therefore be seen as highly relevant in Norway.

The Personal Rapid Transit system (underneath the lifted city area) in Masdar City has proven to become too expensive, of limited availability, and requiring more personnel than assumed for a driverless system. Additionally, Cottrell (2006) claims that more research on the PRT is required before the system can be implemented in a larger outstretch. Due to these findings, and the fact that city expansion is most relevant in Norway, a transportation system connected to existing areas can be seen as more relevant. Therefore also without lifting the city and constructing the transportation system underneath, which is more expensive and harder to implement in existing areas.

Figure 5.3: Bybanen in Bergen (Opeide, 2012)

Mass transportation requires less space than personal transit, and is therefore easier to develop together with roads for cars and pedestrians. “Bybanen” in Bergen (seen in figure 5.3) is one example on such a system being successfully developed in an existing city center. As a conclusion, development of personal rapid transit in existing cities in Norway can be considered to have limited relevance.

The usage of driverless and automated vehicles for mass transit is nevertheless something that can be explored further in Norway. According to Christensen (2014) energy can be saved by up to 30% by using automated transportation systems. On the other hand, the problem in Norway is that public transportation systems are not ideal for people to choose, among some reasons due to the limited capacity (Oslo is an exception with the metro, tram and buses). This again promotes travel by car. The availability of a sufficient public transportation system should therefore be prioritized before automating the systems that are already operational.

Polycentric cities characterize large parts of today’s urban development, also in Norway. The urban area of Stavanger and Sandnes is one example. The two cities have grown together and become one large city area with several smaller city centers. The same counts for Oslo and surrounding areas/cities. These interwoven urban areas emit large amount of carbon dioxide due to great travel distances, low density, and limited options for public transportation outside the city centers. It is however difficult to shrink already sprawling cities, and the implementation of regulations that prevent further sprawl is therefore very relevant in Norway.

Oslo does, nonetheless, have a strict forest boundary, “Markagrensen”, to protect larger forest areas from urban development. Oslo has therefore in recent years had an increasing focus on re-development, retrofitting and infill development in existing urban areas to handle the large population growth. Though improving, many Norwegian cities can benefit from a clearer urban boundary in cities where the population growth is high. Strict urban boundaries can on the other hand, as described in chapter three, also present some challenges in terms of demand and dwelling prices. Both Oslo and Stavanger has a property market characterized by high prices and great demand. A balance between demand and development is therefore also necessary to focus on.

As described in chapter three city development started evolving around the car instead of people in the 1960ties. Two examples of this development in Norway are Forus in Stavanger and Alnabru in Oslo. Figure 5.4 displays a small part of Forus from above. Parking areas surround business areas in an unpleasant pedestrian environment where driving is necessary to reach the location. This type of planning is something Norway should avoid and is trying to change. The planned number of commuters in Masdar City, can therefore be seen as irrelevant for development in Norway. The Ensjø city “Ensjøbyen” in Oslo is an urban renewal project aiming to change earlier development. The motto is “From car-city to a city to live in”, and old factories are retrofitted into offices. Additionally, 5000-7000 new apartments are constructed along with schools and kinder gardens to make it a mixed-use development (Ensjøbyen, 2015).

As a conclusion both limited sprawl and short travel distances are highly relevant for urban development in Norway, hence planning to increase the number of city commuters is irrelevant.

Figure 5.4: A part of Forus seen from above (Nortura Forus, 2010)

With an increasing focus on urban infill and renewal within existing cities the need for easy navigation is of increasing importance. The navigation system in Masdar City has both advantages and disadvantages. The usage of information screens located at different places in the city were one of the positive elements. The distinctive building architecture and the wind tower were others. The implementation of such elements in Norwegian development can definitely be of relevance. Norway does, on the other hand, already use landmarks in city development. The blue stone in Bergen is a good example of a low cultural landmark that is frequently used as a meeting and orientation point (see figure 5.5). An example of an area where increased focus on navigation is needed is the eastern part of Stavanger. All the white, similar sized houses make it difficult to orientate. The navigation system does in other words vary from city to city and area to area. Some might benefit from developing landmarks and some may not.

Figure 5.5: The blue stone in Bergen (Haraldsen, 2006)

As a conclusion, the usage of landmarks, and elements that increase the sense of navigation is of relevance for urban development in Norway, in some areas more than others.

Planning cities for pedestrians and the human scale was, as described in chapter three, normal in earlier centuries. Older urban parts of Norwegian cities are therefore often planned after these principles. The city center and old town in Stavanger is, as seen in figure 5.6, one example. Kvadraturen in Oslo is another. These city areas are small-scale, have short distances and are pedestrian friendly. However, the small-scale houses cannot handle the increasing urban population, which have resulted in the described sprawl. Constructing dwellings that increase city density and at the same time preserve the human scale is therefore necessary, as planned in Masdar City. The original two story houses in Kvadraturen have been exchanged with 4-5 story buildings, and is therefore an example of urban renewal considering both the human scale and the need for increased density.

Redeveloping city centers with small urban houses present some challenges for transformation. This is, among some reasons, due to cultural habits, the need for preservation of existing homes, and cultural heritage. Despite the challenges, several cities aim to develop denser city centers. Unfortunately the human scale is sometimes forgotten or forsaken in the process, and skyscraper-like building blocks are chosen to increase the density and economic gains.

As a conclusion, the relevancy of remembering to develop cities for people and low-rise, human scale is therefore important also in Norway.

Figure 5.6: Old Stavanger (Berge, 2008)

Urban spaces where cars, pedestrians, and bicycles are equally considered can create pleasant urban environments. Planning for bicyclists and all kinds of people is therefore important. As seen in figure 5.7, the streets in Oslo are often without bicycle paths, and the bicyclists have to be constantly aware of the cars, the tram and the pedestrians. The shared space often create dangerous traffic situations, and accidents and even deaths are the result. Bicycle paths are on the other hand more sufficiently developed in Stavanger, where it is possible to bike in separate lanes all the way from Stavanger to Sandnes. This shows that there are variations in Norway, and some areas need improvement more than others. It is however difficult to exclude the cars completely from the urban environment (as seen in Masdar). Developing urban areas where cars have a less dominant role can therefore be seen as more realistic.

Figure 5.7: Bicyclists sharing the road with the tram and cars in Oslo (Dons, 2015; Roald, 2014)

Universal design has gained more and more momentum in Norwegian regulations, and the term "designing for everyone" is an important part of city planning. Nevertheless, many new developments end up as more excluding rather than including. Figure 5.8 displays the stairs outside the new concert house in Stavanger. It is a good example on making something more segregating than universal. The ramp between the stairs is long, inconvenient and time consuming to use. However, even though Norway can improve, Masdar City does unfortunately not set a better example.

As a conclusion, a raised consideration for pedestrians and bicycles can be improved in Norway, and the pedestrian oriented development in Masdar City is therefore relevant. The city´s limited focus on handicapped, mothers with strollers, and others in need for a universally designed area is however unfortunate.

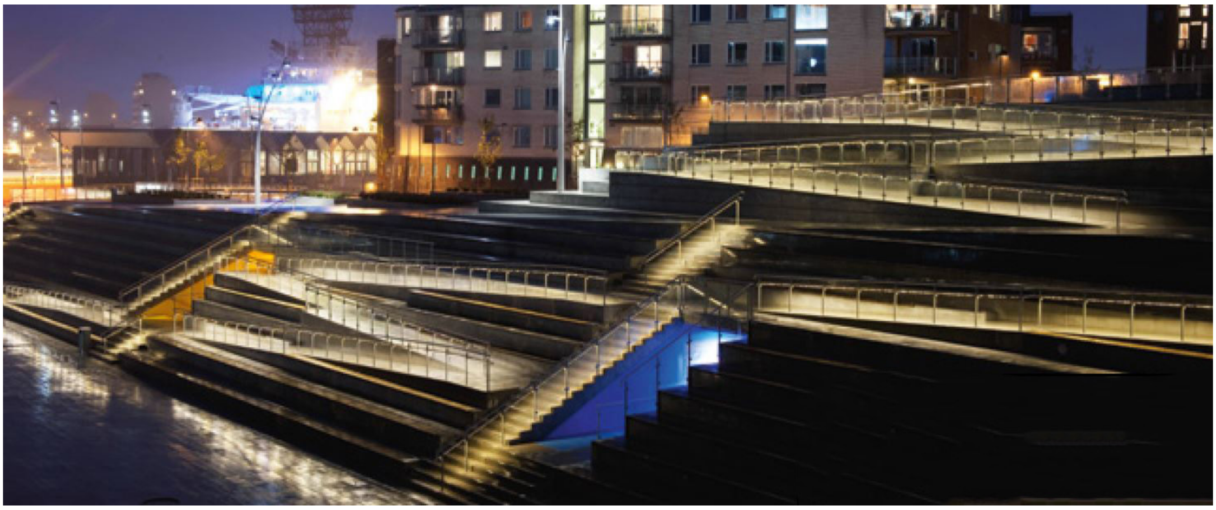


Figure 5.8: Ramp specially designed for handicapped outside Stavanger concert house (Mayer, 2012)

Residential and commercial purposes are divided in many urban areas in Norway. Residential areas do, for instance, surround the business and commercial areas in Forus, without mixing. Figure 5.9 displays the local area plan in a small part of Forus. The plan shows that the areas for business (purple), and residential areas (yellow) are segregated. The same development characterizes the city center of Oslo. The center has a density of 7.4 people per hectare, and consists mostly of commercial, business and cultural activities.

Figure 5.9: Local area plan at Forus (Stavanger kommune, 2011)

Grünerløkka is, on the other hand, an old, low-rise, dense and mixed-use area in Oslo that has obtained increasing popularity recent years. Being one of the densest areas in the city, with 93 people per hectare, it has several cultural and diverse opportunities that makes the area attractive. However, as described earlier, increasing popularity and demand will influence the dwelling price. The people who used to live at Grünerløkka was part of the “working-class”, but the area is now less available for low-income families. All of these examples are nevertheless older developments, and it shows that there have been both successful and unsuccessful developments in Norway in terms of mixed use. It also shows that every development has its disadvantages and advantages, and that a fine balance between different concerns is at the heart of all planning.

As a conclusion, mixed-use development is of relevancy to Norway. At the same time it is important to have in mind that this kind of development also can have its downsides.

The blue and green city structure is something Norway has become increasingly aware of in recent years, both due to micro climate and the increasing problems due to flooding. Oslo does for instance plan to open all natural streams that were diverted in to pipelines when the city was built. Figure 5.10 displays an open stream incorporated into the urban fabric at Nydalen in Oslo. Preservation of forests and other important recreational areas are also considered to be of high priority (hence the earlier described forest boundary in Oslo).

The courtyards in Masdar City were well shaped with greenery and seating, which is important for the micro climate in Norway as well. The need for shade and cooling of the streets is, on the other hand, opposite of Norwegian needs, where optimal sun locations are more important in the cold climate. Shelter from wind and rain underneath the buildings is however more relevant in regions where the weather conditions are rapidly changing, as in the western part of Norway.

As a conclusion, the development of a pleasant micro climate is of importance in Norwegian cities as well as in Masdar. The needs are however different due to climatic conditions. Where water is an important part of the Norwegian city image, shelter from the sun is of equal importance in Masdar. The usage of buildings as shelter, the use of benches in the urban environment, and inclusion of greenery is of relevance for both places.

Figure 5.10: Open stream incorporated into the urban environment at Nydalen in Oslo (I. Moxnes)

As earlier described, cities in Norway are sprawling, and the expanding urban areas are a constant threat to agricultural and forest land surrounding the cities. Developing brownfields and suited land areas is therefore important to minimize the usage of ecological and natural areas.

Masdar City is developed on an earlier brownfield, but the land area did also present some challenges due to the unstable ground. Norway has strict regulations for the location of new development in the government building code (TEK10) (more detailed described in chapter 5.3.3). The reason is to limit the amount of damages and accidents associated with development on unsuited land (that are flooded or have an unstable ground of clay etc.). This means that in terms of geological and natural terms, the regulations in Norway are already strict. Norway can however benefit from cleaning up polluted areas and using them for development. This practice is already used on some areas, but it is still relevant for future development.

5.3 City metabolism – management of resources

5.3.1 Zero waste, sustainable materials and water

Figure 5.11: Waste management in Norway (SSB, 2015a)

10.6 million tons of waste was collected in Norway in 2012, and figure 5.11 shows how the waste was handled. Energy production from incineration is the most common waste management, and 40% of the waste was incinerated in 2012. 36% of the waste was recycled. The recycled materials are paper (97% recycled), glass (91% recycled), metal (99% recycled), plastic (44% recycled), wood (8% recycled), electronics (91% recycled), and concrete (70% recycled). Most of the wood and plastic is incinerated instead of recycled. Only 12% of the collected waste ends up at the landfill, which means that 88% of all wastes are diverted from the landfill in Norway. A new prohibition in 2009 forbid all degradable wastes from being sent to the landfill, and since then the amount of wastes sent to landfill has decreased with 40%. In addition, the capacity for incineration has increased, and the share of incinerated materials is increasing each year (Miljøstatus, 2014a, 2014c, 2014e; SSB, 2015a).

A large part of the Norwegian waste is in other words recycled, or handled in a way that is considered to be more environmentally friendly than landfill disposal. Masdar City is recycling large parts of the construction wastes, but only small parts of the waste produced from operations. The share of recycled wood and concrete is higher than the share in Norway. Norway does however recycle more materials than Masdar City, and even though the share is not 100%, the culture for recycling in Norway can be considered as good. Norway can however improve when it comes to wood and concrete recycling, and the fact that incineration of materials increase each year should perhaps be questioned as the best solution. As seen in Masdar, wood can be recycled at a high rate.

When considering incentives to promote behavior change and consumer responsibility, Norway has developed more incentives than Masdar City. As mentioned in chapter 3, there are no taxes or fees paid in the United Arab Emirates. Norway has fees on curbside recycled wastes and fees on hazardous and larger wastes that are delivered directly to the landfill. These can be considered as good incentives to get people to recycle more (Kipperberg, 2007).

Material	**Approximate percentage**
Bricks	16.2
Wood	18.5
Plaster	11
Cardboard	15.5
Concrete	9.7
Metal	17.9

Table 5.2: Facade building materials in Norway (Lillegraven & Løvik, 2010)

According to Lillegraven and Løvik (2010) the usage of building materials in Norway is approximately as shown in table 5.2. Wood, bricks, and metal are the most common building materials in Norway. They also present several researchers work on the usage of wood within construction, and CO_2 emissions are according to Gustavsson and Sathre (2006) lower when wood is used as a construction material instead of concrete. The Life Cycle Assessment and comparison of wood, steel and concrete performed by Glover et al. (2002) also show that wooden buildings require less energy in their lifetime than the other materials. Börjesson and Gustavsson (2000) do however claim that disposed wood needs to be recycled to obtain the desired carbon balance and manage lower emissions. The reduced carbon effects diminish when the wood is incinerated instead of recycled. According to Kommunal- og regionaldepartementet (2009) the annual usage of wooden materials in Norway only constitutes approximately one third of the annual forest growth. This means that the usage of wood for construction in Norway is both sustainable and can be increased to achieve lower carbon emissions. Disposed wood should however be recycled instead of incinerated, and Norway can therefore aim higher in terms of recycling. It can however be discussed if incineration of wood is the cheaper solution since Norway in general have large areas of forest land.

Approximately 9.7% of all buildings are made out of concrete, and 70% of the disposed concrete is recycled in Norway. The amount of metal used for construction is 17.9%, and 99% of the collected metal is recycled. This shows that Norway does in general use recycled and sustainable materials for construction. Masdar City uses low-carbon concrete and sustainably harvested wood, but Norway is also according to Lillegraven and Løvik (2010) an advocate for sustainable harvesting of tropical forests. Norway has great opportunities for the obtainment of sustainable building materials, and has an already high recycling rate.

Even though there are some differences in waste management in Masdar City and Norway, it is hard to conclude which development is better. Both Norway and Masdar City does recycle metal, paper and concrete at a high rate. Masdar recycles more of the disposed timber, and Norway recycles a wider number of different materials. Both developments have objects that can be improved, and non of them can be called a zero waste city. This does again prove the overall point. Starting this research project was due to the incredible reputation of the Masdar City development. When considering waste management it is hard to distinguish which development is better, hence proving that Masdar City, at this moment, is not a role model for Norway. Compared to the traditional linear city metabolism it can be seen as better, but Norway has in general come a long way when considering waste management. Even though things can be improved, they cannot be learned from Masdar City.

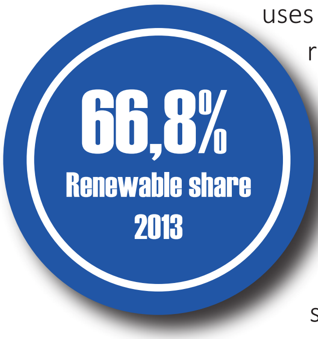
Water in Norway is both treated before becoming drinking water and after it becomes wastewater. The detailed cleaning process varies from county to county, but the main features are the same. The water is obtained from fresh water lakes and then pumped to the cleaning facility. The facility removes particulates, adds calcium to prevent corrosion, and removes bacteria by UV-lighting or/and by adding chlorine (IVAR, 2011a, 2011c; NRA & NRV).

The wastewater is treated in a Conventional Activated sludge systems (CAS) plant where it is treated before being emitted into the ocean or rivers. The process varies according to place of emission, but the rules are in general strict, and contains either a two or a three part process. Removing of large particulates, inorganic materials, and biodegradation of organic material is common. Removal of chemicals is obligatory for wastewater emitted into rivers and other fresh water sources (IVAR, 2011a, 2011c; NRA & NRV). The emitted water products in the three part process has the same standard as the water emitted from the Membrane Bioreactor (MBR) used in Masdar City. Pirani et al. (2011) has however compared the costs and environmental performance of the CAS and the MBR. They conclude that the environmental benefits with the MBR are greater, but the costs and maintenance with a large scale MBR plant are also greater than with the CAS. The emitted water from the MBR is also extremely clean, cleaner than sometimes necessary. Additionally, exchanging all CAS plants would have large negative environmental impacts, and they suggest that measures to reduce the environmental impacts of CAS plants should rather be chosen (Pirani et al., 2011). This means that even though Norway uses conventional treatment plants it would not be economically or environmentally beneficial to exchange existing facilities. New, small-scale facilities can however benefit from constructing the MBR plant in terms of water quality, reduced facility footprint, and reduced environmental impact.

Masdar City reuses 17% of the water for irrigation purposes. Norway does however, unlike Masdar City, hold large amounts of fresh water. The process of cleaning fresh water and making it drinkable requires considerably less energy than desalinating salt water. Recycling of water can therefore be seen as more important in the United Arab Emirates than in Norway.

As a conclusion, the waste management in Masdar City is of limited relevancy to Norway due to the similarities in recycling rate. The same counts for the usage of sustainable materials. Norway has developed more incentives than Masdar City that promote reduced consumption, and the MBR plant is only relevant for construction of new, small-scale facilities.

5.3.2 Renewable energy



In 2013 the share of renewable energy within the total energy consumption in Norway was 66.8% (SSB, 2014c). Since 2005 the share has increased with 8.8% (Bøeng, 2010). This means that Norway uses 31.8% more renewable energy than Masdar City. Within the Norwegian renewable energy production approximately 96 % is from hydropower (SSB, 2013a). In 2013 Norway produced 137,285 GWh of renewable energy, and the total electricity consumption was 128,662 GWh. This means that 7% more electricity was produced than used, and that Norway is self-supplied with electricity (SSB, 2013c). The amount of used electricity within most sectors is high (between 70-80%) (Bøeng, 2010), which means that there is not much room for improvement. The exception is within the transportation sector where, as earlier mentioned, only 1.6% of the used energy is renewable. This means that increased production of renewable energy without increasing the share of used renewable energy will lead to decreased prices. This might again lead to an even higher demand and consumption. Norwegian household consumption is already higher than most countries in Europe, even higher than the USA (SSB, 2015e), and increased consumption should not be promoted. This means that the usage of oil, gas and other non-renewable energy sources need to be replaced with the usage of electricity. The renewable share will otherwise stay the same, and the need for additional renewable energy will be nationally redundant. The excessive produced electricity can however be exported and increase the share of renewable energy in other countries.

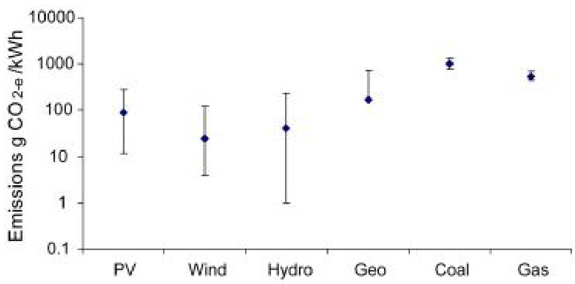


Figure 5.12: Carbon dioxide equivalent emissions during electricity generation (Evans et al., 2009)

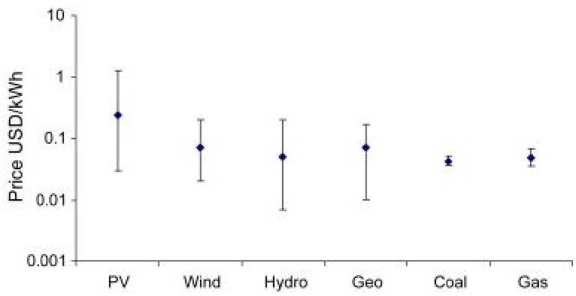


Figure 5.13: Cost of electricity generation per kW h. (Evans et al., 2009)

Photovoltaic	4-22%
Wind	24-54%
Hydro	>90%
Geothermal	10-20%
Coal	32-45%
Gas	45-53%

Table 5.3: Efficiency of electricity generation (Evans et al., 2009)

Nevertheless, for Norway to produce more renewable energy, it needs to be environmentally and economically beneficial. Evans et al. (2009) has conducted research on the costs, efficiency and environmental benefits of different renewable energy sources. Their findings are presented in figure 5.12 and 5.13, and table 5.3. Figure 5.13 shows that hydropower and other renewable sources are in general cheaper than photovoltaic power. Emissions are inevitable, also from renewable energy sources, and figure 5.12 shows that the emissions from wind power are the lowest, followed by hydropower and solar power. Table 5.3 shows that the efficiency of hydropower is over 90%, whilst the efficiency of PV power only is between 4% and 22%. Furthermore, figure 5.14 shows that solar radiation in Norway is low compared to other places in the world due to the country´s location. The annual solar radiation in Norway varies from 700 kWh/m^2 in the north to 1100 kWh/m^2 in the south. The daily radiation varies from 5500 Wh/m^2 to less than 4000 Wh/m^2 in the summer, and from 350 Wh/m^2 to less than 50 Wh/m^2 in the winter.

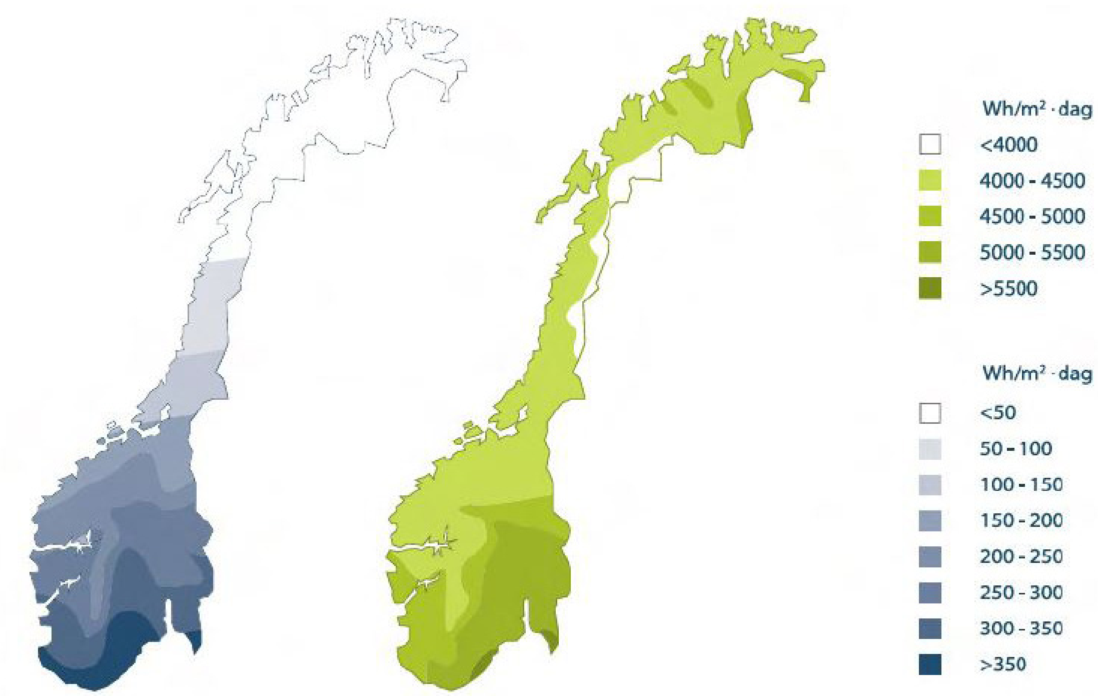


Figure 5.14: Sun radiation against the horizontal plane in January and July (Barstad)

This means that there are large variations within the country, and seasons (Rindal & Salvesen, 2009). Photovoltaic power generation is therefore not the most ideal solution for power generation in Norway.

Moreover, the Norwegian Water and Energy Directorate (NVE) (2015c) claims that about 60% of the hydropower potential has been developed, which means that there is room for expansion of hydropower generation in Norway. The country also has some of the most ideal wind conditions in Europe (NVE, 2014). All of these findings show that the most economically and environmentally beneficial solution for Norway, would be to extent the country´s renewable energy production within hydropower or wind power.

Several cabins in Norway are however using photovoltaic panels for electricity production, and places where the connection to the national grid is non-existent can benefit from using rooftop photovoltaic panels (NVE, 2015a).

The conclusion is that even though the Norwegian climate might not present the same requirements for maintenance as in Masdar City, it is still not beneficial to develop large scale PV power facilities. Within the terms of efficiency, environmental performance, and economic benefit it is better to choose other alternatives.

The Beam-Down Solar Thermal Concentrator in Masdar City is more relevant than the photovoltaic panels for large scale energy production because it has the capacity of storing the generated heat. It is nevertheless, as mentioned above, still more relevant to develop other renewable energy facilities. The space requirements do also make it impractical for personal energy production, and totally this means that the facility is of limited relevancy to Norway.

5.3.3 Smart building design - energy and water consumption

As earlier mentioned buildings consume approximately 38% of the used energy in Norway. Even though buildings use mostly renewable energy, reduced energy consumption means that more clean energy can be used in other sectors, regions or countries. Hence reduced energy consumption in buildings will reduce carbon emissions, which again will contribute positively in achieving the goals set by the Kyoto Protocol. Additionally, the building sector can, according to Lillegraven and Løvik (2010), manage to reduce emissions in a relatively cost efficient way compared to other sectors.

The Norwegian building code (TEK) in the Norwegian Planning and Building Act is concerned with the energy usage and energy efficiency achieved in new buildings. The building code contains a number of detailed specifications for building construction (Lovdata, 2010). In 2007, the Norwegian government presented a new climate policy, "Klimaforliket", where long-term goals for climate gas reduction was introduced. The climate policy says that there should be an increased investment in energy efficient buildings. It also says that the technical building code (TEK) should be updated more often, and that the introduction of a passive house standard within 2020 is in progress. TEK7 was presented as a result of this, and the requirements state that all new buildings shall use 25% less energy (Kommunal- og regionaldepartementet, 2009; Lillegraven & Løvik, 2010). TEK10 is an updated version that has continued these requirements.

In addition to the building code, several other measurements have been implemented to reduce energy consumption in buildings.

Numerous Norwegian cities attend in the investment project "Cities of the future" led by the Environmental Department (Miljøverndepartementet). The project has four priority areas, and one of the targets is to develop pilot building projects with low energy consumption (Kommunal- og regionaldepartementet, 2009).

Figure 5.15: Bellona building in Oslo (I. Moxnes)

Enova is a firm owned by the Norwegian energy and oil department, and it contributes to the restructuring of energy usage and production. The firm has developed several support programs for innovative energy solutions, new technology, and buildings (Enova, 2014).

The Norwegian water and energy directorate (NVE) introduced an energy labeling scheme for new buildings in 2010, which makes it obligatory to provide all new buildings with an energy certificate. The certificate consists of an energy mark, displayed in figure 5.16, that stats how much energy the building requires (NVE, 2010). The Bellona building in Oslo, as seen in figure 5.15, is certified with an energy mark A in the labeling scheme. It is also a certified passive house. All aspects regarding energy usage, materials, transportation to the building, and impacts on the climate were carefully considered when the building was constructed. The building uses approximately 50% less energy than the requirements in TEK10 (Norske arkitekters landsforbund, 2015).

Figure 5.16: Energy efficiency mark (NVE, 2010)

All of this means that the Norwegian government is constantly working to update building requirements, and that several measures to reduce energy consumption in buildings are introduced and under development.

Garder (2010) has studied the differences between Norwegian building regulations and the green building rating system, LEED. He claims that a comparison between the two can be misleading because the systems basis and purpose are different. The Norwegian TEK10 aims to control that buildings are constructed according to certain requirements. LEED, on the other hand, is as system that is meant to encourage environmentally friendly construction. He does nevertheless conclude that TEK10 does address all the subjects evaluated in LEED. TEK10´s requirements can be seen as satisfactory in terms of energy efficiency, location requirements, and indoor climate, whilst it can be improved in terms of materials and resources, and water efficiency.

It is however more appropriate to compare LEED to the energy labeling scheme introduced in 2010. The scheme does, as LEED, aim to consider the environmental effects of construction. The system only includes energy, which is only a part of LEED, that includes all the above categories compared to TEK10. The category concerning energy does, nonetheless, include 35 of the 100 available points. This means that energy efficiency is the most important subject within LEED (Garder, 2010).

Norwegian building requirements, both TEK10 and the energy labeling scheme, does in other words promote many environmentally friendly solutions. Norway does however not have a complete green building rating system, like LEED, BREEAM and Estidama, but the introduction of such systems can have both advantages and disadvantages. Both LEED and BREEAM are adjusted according to American and British building standards. The system should therefore, if implemented, be adjusted after Norwegian conditions. As seen in Abu Dhabi, and Masdar City, a system with specifications for the arab environment has been developed. The positive sides with implementing a system that considers all the environmental aspects with construction is that each building receives a brand that can be compared to other buildings. This might raise awareness, and possibly also competition to become more environmentally friendly. As seen in figure 5.17, the LEED Platinum sign outside Siemens Headquarters has definitely become a brand for everyone to see.

Figure 5.17: Sign outside Siemens Headquarters (I. Moxnes)

The features in Masdar City displaying energy and water consumption can be positive in terms of reduced energy consumption. It might however be problematic in Norway to monitor private homes in terms of energy usage. There must in case be some requirements in terms of confidentiality. Nevertheless, information does in general raise awareness, and people tend to choose environmentally beneficial solutions if they are informed of the possible impacts. Implementing features similar to those in Masdar might therefore be an interesting next step also in Norway. This can establish collective goals, enlighten the citizens, and gather participants working for a more sustainable society.

As a conclusion the requirements for passive and intelligent buildings in Norway are already quite satisfactory, but still relevant for future development. The implementation of an holistic green building system specific for Norwegian conditions is relevant, and is something that is already being explored. The features to promote awareness and reduced consumption are interesting, and though not operational in Masdar at the moment, still relevant for development in Norway.

Strategies to become a low carbon city	Masdar City goals	Masdar City reality 2015
Sustainable city planning and urban form		
Equal focus on environment, equity and economy	1/1	0/1
Sustainable urban form	10.5/12	5.5/12
High density	Yes	No
Good public transportation system	Yes	No
Short travel distances	Yes	Yes
Limited sprawl	Yes	Yes, at the moment
Short distances to surrounding areas	No	No
Easy navigation	Yes	To some extent
Pedestrian/bicycle friendly	Yes	Yes, but not universally designed
Mixed use	Yes	Yes and no
Low rise	Yes	Yes
Design for micro climate	Yes	Yes
Developed on suited land areas	Yes and no	Yes and no
Inclusion of natural elements	Yes	No
Circular city metabolism		
Zero waste, sustainable materials and water	4/7	2/7
100% resource recovery from waste	No	No, only some
Zero landfill and incineration	No	No
100% recycling of waste	Yes	No, but 60% of construction wastes
Extended producer and consumer responsibility	No	No
Behavior change and sustainable consumption	Yes	No
Treatment and recycling of water	Yes	Yes, but not sustainably produced
Use sustainable and recycled materials	Yes	Yes
Renewable energy	3/3	1.5/3
Photovoltaic (PV) solar panels	Yes	Yes and no
Concentrating solar plant (CSP)	Yes	Yes, but in a limited extent
Windmills etc.	Yes	No
Smart building design - energy and water consumption	5/5	4/5
Energy efficient	Yes	Yes
Reduced water consumption	Yes	Yes
Monitoring and control systems	Yes	Yes
Using natural airflows	Yes	Yes
Features to increase awareness and decrease consumption	Yes	No

Table 5.4: All gathered results, and the relevancy of Masdar City for low carbon urban development in Norway (I. Moxnes)

Relevancy to Norway
0/1
7.5/12
No
No
Yes
Yes
No
Yes, but in some areas more than others
Yes, but not in terms of universal design
Yes, but with certain considerations
Yes
Yes, but with some different considerations
Yes and no
No
1/7
No
No, but less incineration should be considered
No
No
No, Norway has more incentives
Yes, but only for new, small-scale facilities
No
1/3
No
No
Yes
5/5
Yes, but Norwegian requirements are already good
Yes
Yes
Yes
Yes, even though they were not operational in Masdar

5.4 Final presentation of the results in the main table

Table 5.4 displays all the gathered results in this thesis; Masdar City goals compared to theory, the Masdar City reality, and the city´s relevancy to Norway within each category. The table shows that 7.5 of the measures within urban form are of relevance to Norway, and that only one of the measures within zero waste and renewable energy is of relevance. Windmills have a positive conclusion in the renewable energy category even though they are not present in Masdar City. This is because presenting a negative conclusion could be misleading when this form for energy production can be seen as relevant in Norway. The only category with a full score is smart building design.

6. Discussion and conclusion

This thesis has researched the relevancy of Masdar City for low carbon urban development in Norway. It investigates what measures that are planned to reduce carbon emissions in Masdar City. Further it studies if these measures are fulfilled and working as intended. Finally, it investigates if the measures are relevant to Norway. The idea of a low carbon city is important because cities are responsible for 70% of the world´s carbon emissions. A claimed answer to these problems should therefore be investigated and put in to question before other cities adopt similar strategies.

The planned measures of Masdar City, and if the developed measures are working as intended, are presented in chapter three and four, respectively. Chapter five presents the investigation of the developed measures relevancy to Norway. A summary of the results are presented in table 5.4. This chapter aims to discuss and synthesize the gathered results and answer the main thesis question:

> *"Are the measures made in Masdar City relevant for low carbon urban development in Norway?"*

This will be accomplished by first presenting the thesis empirical findings shortly. Secondly these findings will be discussed and scrutinized to present an overall meaning. Furthermore the chapter will implicate how the findings are important for the understanding of the concept of a carbon neutral versus a low carbon city. A suggestion for further research will be presented. Finally, the used methods will be discussed in terms of reliability and validity.

The results show that some of the measures made within urban form and building design in Masdar City are relevant for urban development in Norway. The measures made within waste management and renewable energy are nevertheless of limited relevance.

Norway has in this thesis proven to be above average or perhaps even one of the best countries in the world when considering both renewable energy production and waste management. The next step for Norway to develop low carbon cities is therefore to implement stricter regulations for the urban form and the cities´ coherent buildings. These categories were proven to obtain the most successful measures in Masdar City. However, the extent of the developed urban form in Masdar City can be described as very small, and due to this the relevancy of each individual finding can be seen as more unreliable. A fully developed city area with a more significant number of inhabitants, would present a more realistic urban form. For instance in terms of sprawl. Additionally, the measures that will result in significantly reduced emission in Norway are unsuccessfully developed in Masdar City. Then especially referring to public transportation, travel distances to surrounding areas, and the density. The measures made within building design are therefore left as the only relevant part, and it can be questioned if this part alone makes the city relevant for low carbon urban development in Norway. Several measures need to be successful to make a low carbon city. The few relevant parts therefore become irrelevant when considering the overall performance and relevancy for urban development in Norway.

Both Masdar City and Norway are however relevant for other developments that have implemented fewer measures to reduce carbon emissions. The developments have both successfully reduced the amount of wastes sent to landfill, implemented renewable energy sources and constructed smart buildings. The comparison of Masdar City to Norway, that has already successfully implemented measures to reduce carbon emissions, will naturally make the city less relevant than if compared to a development with less satisfactory results.

The overall goal in Masdar City of becoming carbon neutral and zero waste should nevertheless be put into question. The city has failed in reaching its goal of becoming zero waste and in implementing many of the other ambitious goals set by the original plan. Premalatha et al. (2013) also conclude that Masdar City has failed in becoming a zero waste development, and they claim that one of the reasons for this is that a zero waste target is physically unattainable. When aiming for unreachable goals, the result will always become less satisfactory. Aiming to recycle as much as possible and promote reduced consumption would both make the goals more achievable, and put the development in a more plausible light.

The limited achievements do however not mean that the city has failed in becoming carbon neutral. The reason for this is the earlier mentioned possibility of becoming carbon neutral by offsetting the city´s emissions. The same goal is, as mentioned, set by the Norwegian government to reach within 2030. Is it good practice to forsake geographical city measures and fulfill goals of carbon reduction by improving upon others?

As seen in Masdar City, the concept of carbon neutrality removes the responsibility for the city to actually reduce the city´s emissions. Norway has large emissions from transportation due to the limited amounts of used renewable energy within this sector. The same counts for Masdar City. If the carbon neutral concept does not alter current planning measures that contribute to large carbon emissions, is it then a plausible goal?

Perhaps it is not possible to develop a completely zero carbon city in a modern world where the economic development and the amount of travel is high. Nonetheless, the goal has to address the actual problems if reduced emissions are to be managed in the most optimal way. Offsetting can be seen as the easy way out, which seldom presents the solution. As seen in Masdar, it leaves a less satisfactory result within the city´s geographical boundaries. It is not that the concept of supporting more sustainable solutions in other parts of the world is bad, but removing the responsibility from the country or city in question does not promote change. If all carbon emission organs (cities or countries) disunite the problem and aim to improve upon others, there will be no one left to examine themselves. The overall point of this thesis is therefore that the concept of carbon neutrality should in general be reconsidered as a development goal. Other more realistic and direct goals, as low carbon development, should be used instead.

An interesting recommendation for further research is therefore to study how the current belief of carbon neutrality as a credible goal can be reconsidered in a worldwide context.

This thesis has provided an overall evaluation of several elements within a city that together can reduce the amount of emitted carbon dioxide. A direct consequence of the scope of this thesis has presented some limitations for the study that need to be considered. The extent of the study limited the options for an in depth study of each individual part within for instance urban form. Each of the minor groups within this category could have been the subject of a whole thesis dissertation. This naturally then presents some challenges in gaining the needed depth in the study. Nevertheless, the thesis has gained the needed information to answer the thesis question. The requirement for a deeper study of all the parts can therefore be seen as unnecessary in terms of this thesis.

Another possible limitation is that the empirical study could have been strengthened if the work of more researchers had been used. This would have presented a more solid background for the comparison of Masdar City to Norwegian conditions. Some might even claim that the results would have been different if other researchers work had been used. On the other hand, the used references within waste management, renewable energy and smart building design are from reliable statistical and professional Norwegian databases. When these are combined with other researchers work, the result can be seen as strongly feasible.

The main table as method presents the opportunity to intertwine and include relevant theory into all parts of the thesis. It also presents the opportunity to get a broader perspective and overview of the goals, the reality and the relevancy to Norway. Creating the sub-categories according to Masdar City goals and the minor groups according to theory also made it possible to only include relevant and interesting theory that could support or falsify the original concept.

Nevertheless, a limitation with the theoretical background is that the original goals of Masdar City presented the ground for choosing relevant theory. Since the theory was chosen according to the plans, other theories might have been overlooked. As mentioned in chapter three, there are several opinions on how to develop a sustainable city. For instance, the details in the theoretical background for a zero waste city varies according to the researcher. However, even though only the chosen researchers work were presented, other definitions have been considered to find the most common perception. Even though these are not presented, the thesis has undergone a constant evaluation to present the most plausible results.

The overall comparison between several subjects, several researchers work, relevant theory, and personal knowledge does in general present a thesis with a valid and reliable result. In the end, all parts of this thesis are linked together to present the limited relevancy of Masdar City for low carbon urban development in Norway, and the limitations presented by both developments carbon neutrality goal.

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