Going to climate neutrality – environmental technologies used in eco-cities on the examples of Tianjin Eco-city and Masdar

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Abstract

The purpose of the article is to investigate the differences between ecological solutions saving energy used in eco-cities on the examples of Tianjin Eco-City and Masdar City. The paper is based on the systematic literature review. Literature was collected, then the background of both cities' creation and their location were highlighted. Afterwards, the authors compared both cities in terms of environmental technologies applied in the cites. Four aspects, namely renewable energy, waste management, water economy and transport were considered.

Key words

eco-city, climate neutrality, ecological solutions, Sino-Singapore Tianjin Eco-City, Masdar City

Introduction

The idea of eco-city idea spread at the begging of XXI century. Among the examples of eco-city projects are Gwang Gyo in South Korea, Destiny Florida in the USA or Tangshan Caofeidian in China. The eco-city is strongly related to sustainability, reducing the negative impact on environment and using green energy sources.

There are three pillars which should be equally taken into consideration, while building such city: environment, economy, society. Bibri (2021) points five groups of environmental and economic benefits of the eco-city – green infrastructure, sustainable energy systems, sustainable waste management systems, usage of sustainable materials and green technology development [Bibri, 2021, pp. 11-12]. An important aspect of this concept is an application of different technologies, for instance: desalination, pneumatic waste collection systems or energy saving sensors. Equally significant are factors like waste generation at minimal level and recycling, providing comfortable houses at affordable prices and focusing on developing public transportation.

The idea of eco-cities development is in line with the trend towards increasing climate neutrality and decrease the global warming effect [Paris Agreement, 2016] as globally more than 70% of the world's resources and energy are used in cities and cites are responsible for production more than 70% of wastes and 70% of greenhouse gases emission [Huovila et al., 2022, pp. 2]. Climate neutrality means the economy with net-zero greenhouse gas emissions (reduction of emissions in industry, transport and energy, and balancing the emissions that have not been reduced by increasing absorption thanks to, for example, the development of new green areas) [Dębkowska et al., 2022, pp. 3-4; Szpilko and Ejdys, 2022]. Nowadays, climate change has become the most crucial environmental challenge facing the world [Dioha, 2020, pp. 32]. For instance, the European Union targets are reduction of the greenhouse gas emissions and increase in energy efficiency [Panait, 2017, pp. 60]. The other circumstances that influence energy systems, besides need to reduce carbon emission, are the political controlled fossils resources and danger of a war [Octavian and Silviu, 2018, pp. 87] – as an example – Russia attack on Ukraine in 2022 and its impact on energy systems in other countries.

The issue of eco-cites becoming is more and more popular in scientific research. Khalid and Radi Abaas (2021) point the main characteristics of eco-city projects in England, China, Finland, Spain, the US, and Germany, showing that Europe focused more on preserving nature and natural resources, China on the economic aspect (first improving job opportunities and then the living environment) and in America the emphasis is on technology and intelligence in the green design [Khalid and Radi

Abaas, 2021, pp. 17, Szpilko et al., 2020]. Huovila et al. (2022) present comprehensive literature review on the concept and its practice realization on example of Finnish cities [Huovila et al., 2022]. Joss et al. (2012) present elements and functions of indicators on example of nine eco-city projects [Joss et al., 2012, pp. 113]. Zhan et al. (2018) compared Chinese projects – Sino-Singapore Tianjin Eco-City and Shenzhen International Low Carbon City, showing the similarities and differences in initiative financing and involvement of stakeholders [Zhan et al., 2018, pp. 6]. In turn Zou and Li (2014) contrasted indicators related to some sustainability indicators in Chinese eco-cities with Japan and German eco-cites [Zou and Li, 2014, pp. 23-24].

However, in available research there is lack of comparisons of ecological solutions indicated in eco-cites, especially with references to cities location in various climates. The question is what ecological solutions aiming at improving climate neutrality are applied in different in cities and does ecological solutions application differ according to climate? The purpose of the article is to investigate the differences on the examples of Tianjin Eco-City and Masdar City as examples of monsoon and arid climates cities. Four ecological aspects, namely renewable energy, waste management, water economy and transport were considered.

The paper is structured as follows. Firstly, the authors explained the meaning of eco-city term and aspects which must be included in that kind of city, the background of both cities' creation, their location and main assumptions were highlighted. Then the research aim and methodology is presented. Furthermore, the authors compared both cities in terms of renewable energy, waste management, water economy and transport. Finally, conclusions and recommendations for further research are listed.

1. Literature review

1.1. The idea of eco-city

The eco-city term was first presented in 1987 in the book titled Eco-city Berkeley: Building Cities For a Healthy Future by R. Register [Wong and Yuen, 2011, pp. 3]. The eco-city is described as "an ecologically healthy city, a sustainable city, an energy-efficient city, a low-carbon city, a smart energy city, and an ecosystem whose structure and function are self-sustaining and resilient" [Wu et al., 2020, pp. 5]. The concept contains diverse ecological, socio-technical ideas which are focused on reduction of negative impact on environment and are the key for transforming cities into places characterized by low-carbon emission.

Register defined eco-city as "an urban environmental system in which input (of resources) and output (of waste) are minimized" [Gürel Ulusan, 2017, pp. 872; Register, 1987, pp. 6]. However, Jabareen (2006) points that eco-city term defines not only wide-ranging new cities but also small urban projects [Jabareen, 2006, 46-47]. The eco-city is being described as environmentally healthy city [Khalid and Radi Abaas, 2021, pp. 2]. The reason of that is the fact of covering a wide range of pro-ecological solutions, which ensure urban sustainability [Bibri and Krogstie, 2020, pp. 3]. These include green energy (which descend from natural sources e.g., wind, geothermal, solar, hydropower, oceanic, biomass) [Bibri, 2020, pp. 2], water and waste management [Kenworthy, 2006, pp. 68]. Moreover, existing technologies help to accomplish these goals. Smart solutions like smart grids, digital information and contribution technology are being implemented to form, control or lead the whole eco-city [Joss and Molella, 2013, pp. 119].

When building such a city three pillars should be considered as equally important: environment, economy, society. To reach that, there are many aspects which should be included [Griffiths and Sovacool, 2020, pp. 1-2]:

- broadening of society knowledge by educating about excessive material goods usage;
- providing safe, comfortable housing at reasonable prices;
- raising public awareness regarding recycling and the importance of reducing pollution;
- encouraging enterprises to function in concordance with principles of ecology;
- local agriculture supporting and spreading the idea of common gardening and development of green areas;
- functional and well-thought-out distribution of urban facilities;
- constant improvement and promotion of public transport;
- providing equal chances for citizens and improving possibilities for needy people.

Gürel Ulusan (2017) underlines other factors, influencing development of eco-cities such as [Gürel Ulusan, 2017, pp. 876]:

- balanced urban development;
- green energy sources;
- reducing the impact on environment;
- minimalizing the level of waste generation;
- bioregionalism;
- sustainable technology.

According to Huovila et al. (2022), eco-cities are characterized by using public transportation and promoting going on foot [Huovila et al., 2022, pp. 3]. Another aspect are mixed-use districts which are supposed to prioritize land reusing. The authors also name factors which are important while building eco-city [Wong and Yuen, 2011, pp. 33]:

- excluding cars policy,
- renewable energy sources,
- biodiversity,
- green tools which help to attain sustainability,
- building up eco-city strategy.

Joss (2011) makes a distinction in eco-cities projects between: projects related to expansion of existing urban areas, project of sustainable development (adaptation) of existing infrastructure and newly developed cities (like for example Tianjin Eco-City and Masdar City) [Joss, 2011, pp. 272].

1.2. Tianjin Eco-City and Masdar City – examples of eco-cites

Sino-Singapore Tianjin Eco-City (SSTEC) an example of city located in monsoon climate. It is a cooperative project between China and Singapore National Governments located 45 km from Tianjin and 150 km from Beijing city [Liu et al., 2018, pp. 367] in the Tianjin Binhai New Area which is one of the fastest growing regions in China. The project was initiated in 2007 during Chinese Premier Wen Jiabao visit in Singapore, where it was formalized with Singaporean Prime Minister Lee Hsien-Loong, becoming the second government-to-government eco-city project between China and Singapore [Hu et al., 2015, pp. 5]. It is required for the eco-city's location to highlight the value of eco-city construction under conditions of limited resources and on nonagricultural land. That is why SSTEC is being built on relatively poor land such as deserted saltpans, polluted water bodies and lack of freshwater area [Ji and Shen, 2014, pp. 952].

The concept is based on three harmonies: between people and environment, between people and economic activities and among people, and is designed to be practical, replicable, and scalable [Yang and Deng, 2013, pp. 112]. The official target of this initiative is to create a model of eco and low carbon city for future expansion in China. It promotes recycling of resources and using renewable energy sources by innovative technologies, environmentally friendly policies and many investments on water, transport, energy and land sectors. Issues like global climate change and social equity are also included in the plan by affordable housing and reduction of greenhouse gas emissions [Word Bank, 2009, pp. 2].

As a northern China city, SSTEC lays in climate where summers are warm, but they bring 70% of precipitation, while during other months of the year it is very dry. The city is situated 500 m away from Bohai Bay's only dam, where historically strong tide had hit part of the site so still, future extreme weather events are threatening this area. Furthermore, in the center of Tianjin Eco-City there is Qingjing Lake which in the past decades was used as an industrial wastewater basin. Likewise, through SSTEC flows the Jiyunhe old river which water's quality was among the worst before reconstruction and transformation [Tao and Zhengnan, 2013, pp. 409-413].

Technology, in form of various "green" solutions, is an inseparable part of eco-city. Among many technological ideas applied in SSTEC, there is pneumatic waste collection system which is capable of waste sorting in three sections – to recycle, to transform into methane gas and to deposit to a landfill [Joss and Molella, 2013, pp. 125].

Usage of renewable energy sources is conditioned by geographical position and available natural resources. Exemplary, there is no point building large-scale wind power systems, due to small amount of harvestable wind. On the other hand, abundance of geothermal resources in the region is the main reason why geothermal energy is going to be crucial system in Tianjin Eco-City. Solar power will be used as a water heating system in households and as a local electrical supply. There are also other renewable energy sources applied in SSTEC, such as biomass, natural gas or even electricity generated by vibrations of vehicles. Because of seasonal changes, adaptation of specific source of energy is very flexible [Hu et al., 2015, pp. 8].

The city is planned to cover an area of 30 square kilometers with predicted overall investment worth 50 billion yuan (contrib. $7.83 billion). The population is intended to reach 350 000 people [Zhang and Jin, 2010, pp. 10].

The other example of eco-city is Masdar. In Arabic the word "masdar" means "source". The city's name indicates its signification as a source of many of the basic resource categories, with particular knowledge and innovation meaning, especially in the very important area of clean technologies and renewable energy sources in this geographical region [Dziedzic, 2015, pp. 270]. Masdar is located in arid climate.

The Masdar Initiative was created in 2006. The Masdar project is a consequence of Abu Dhabi government decision to develop renewable energy technologies. As a city which will be a worldwide example of implementation of innovations and sustainability [Hartman et al., 2009, pp. 1], its aim is to use Abu Dhabi's purse and knowledge to create more innovative solutions regarding "green" energy and resources protection.

During Masdar city creation the following programs were highlighted:

- real estate development unit – which aim was the supervision over the construction of the city with focus on sustainable development;
- industries – with aim of investing in renewable technologies and later transporting them to Abu Dhabi;
- carbon management – working on projects based on capture and storage of carbon dioxide (CO_2) and using it in hydrogen-fired power generation technology;
- utilities and asset management – with the main objective to operate wind and sun power plants;
- Masdar Institute of Science and Technology concentrating around science and engineering of high-end and sustainable technology.

The above points arose from Abu Dhabi's objectives. First was to help in the economic diversification of Abu Dhabi. Transforming the country into a creator of technology rather than an importer of it and development in energy markets – maintain and later expand global position. Finally, contribution to human development [Mezher et al., 2010, pp. 753].

Masdar not only fully meets the energy needs of the entire city, but also is able to produce the surplus of energy and transport it to Abu Dhabi. The technologies used for power generation are photovoltaic, geothermal energy and green energy. Masdar City has an efficient wastewater treatment and water recycling system in place. Proper waste management ensures literally that waste is not produced because it is all managed [Dziedzic, 2015, pp. 269].

The city is designed for 40 000 people and located 17 kilometers East-South of Abu Dhabi. Masdar covers an area of 7 square kilometers [Tourani and Jamshidi, 2016, pp. 3124]. First projects assumed building Masdar as a zero-carbon city, but the model has been changed and focused on carbon neutrality. The concept at the beginning was "self-develop and hold", but in 2010 the project entered into extensive use of outsourcing and strategic partnerships [Griffiths and Sovacool, 2020, pp. 2].

2. Research methodology

The purpose of the article is to investigate the differences between ecological solutions in monsoon and arid climates eco-cities on the examples of Tianjin and Masdar.

The paper is based on the systematic literature review. Firstly, procedure for literature review was elaborated – the choice of databases and criteria for paper inclusion were settled. In the study, the academic journal articles from Web of Science data base, from year 2007 to 2021 and written in English were chosen. The articles

with terms "Tianjin Eco-City" or "Masdar" in the title were selected. Then titles and abstracts of the papers were checked what enabled to remove the unrelated literature and reduced the number of articles to 33. Then, papers were taken for detailed screening. This step allowed for comparison of Tianjin Eco-City and Masdar City in terms of renewable energy, waste management, water economy and transport usage. The results are the identified differences between ecological solutions in monsoon and arid climates cities. The steps of creating the literature database are in Table 1 and the research methodology is presented on Fig. 1 (based on [Okoli, 2015; Piotrowicz et al., 2021]).

Tab. 1. The steps of creating the literature database

Number of articles in database	**Tianjin Eco-City**		**Masdar**	
	Rejected	Received	Rejected	Received
With city name in title	-	40	-	48
After titles and abstract checked	27	13	28	20
Chosen for detailed screening after full text reading and studying the reference search for papers	5	8	4	16

Source: authors' study.

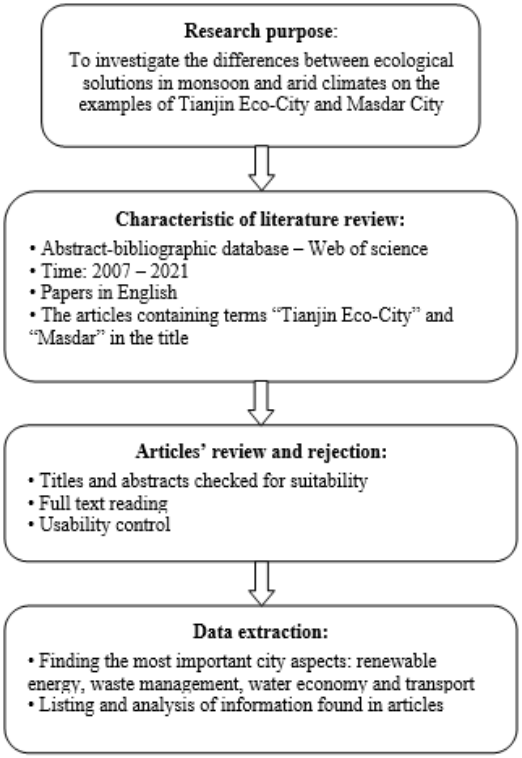

Fig. 1. Research methodology

Source: authors' study.

3. Results

The Tianjin Eco-City and Masdar City as the examples of eco-cites located in monsoon and arid climates were compared in terms of renewable energy, waste management, water economy and transport usage. The ecological solutions used in both cities are listed in Table 2.

Masdar energy sources are focused on CSP (Concentrated Solar Power) – 100 MW farm uses sunlight to fulfil residents needs of the city. In addition, the sunshine is also used by solar photovoltaic panels on rooftops of the houses [Lee et al., 2016, pp. 1301]. Research suggest that using small wind turbines is reasonable move in the city, but the information about usage of this technology in Masdar has not been found [Janajreh et al., 2013, pp. 14]. The city takes part in multiple projects around the

world but does not have wind technology implemented [https://masdar.ae/en/masdar-clean-energy/technologies/wind, 09.11.2022]. Additionally, every building in Masdar will be equipped with movement sensors installed instead of water taps and light switches to reduce electricity and water usage by 51% and 55% [Lee et al., 2016, pp. 1304]. In Sino-Singapore Tianjin Eco-City there is also a solar panel plant which supplies surrounding buildings. Solar panels also produce electricity for lighting public roads. Moreover, solar energy is used to assist wind turbines which are located at the entrance to the SSTEC [Li et al., 2018, pp. 92], but according to wind conditions it is not worthwhile to implement this technology on large-scale [World Bank, 2009, pp. 28]. Additionally, in the city there are fifty geothermal pumps located around the buildings and work with air exchanger as an air-conditioning system [Li et al., 2018, pp. 92].

As for waste management, Masdar is predicted to be a city minimalizing waste. Moreover, the city is expected not to have relevant impact on environment and soil resources [Cugurullo, 2013, pp. 33]. Residents are provided with conditions to a zero-waste lifestyle by reducing, reusing, recovering and recycling waste materials. By doing so, Masdar wants to create a zero-waste community [Madichie, 2011, pp. 43]. There are many ways to recycle, depending on waste type. For example, an industrial waste is being used instead of cement to make concrete stronger [Zhu et al., 2012, pp. 1006], old concrete is being used to building roads. Another point of recycling is wood which is being shredded and mulched. In Masdar exists a large recovery plant where the city's solid waste is being recycled and composted [Patel and Griffiths, 2013, pp. 450]. Challenging aspect is e-waste recycling, because of electronic gadgets, such as smartphones, computers and others. Masdar exports them to outsourcing recycling [Randeree and Ahmed, 2019, pp. 143]. Pneumatic waste-collection system, which is a high-tech mechanism, is the main solution of recycling waste in Tianjin Eco-City. Thanks to that, in the city, there will not be any garbage trucks or recycling trucks. Waste are forced underground and ejected from the eco-city to an incinerator site directly from the apartments [Caprotti et al., 2015, pp. 509]. In masterplan there are five collecting chutes and collection places in every residential quarter. For using the system, residents collect points which give them credit in local shops [Li et al., 2018, pp. 92].

Tab. 2. The solutions of renewable energy, waste management, water economy and transport used in Tianjin and Masdar eco-cities

TIANJIN ECO-CITY				
Author	**Renewable energy**	**Waste management**	**Water economy**	**Transport**
Li et al. (2018)	solar, geothermal and wind energy sources, windows for air circulation, natural light, geothermal pumps for air-conditioning	controlled flushing in bathrooms, pneumatic rubbish collection	water infiltration by lawns and porous paving to underground reservoir, canal's lock system, water treatment plant	limited vehicle number, controlling vehicular entry, prompting non-polluting mobility and public transport
Caprotti et al. (2015)	utilization of heat emitted from industrial sources	pneumatic waste-collection system	water filtration and purification	prompting public transport and walking, only fuel-efficient vehicles in the center
Flynn et al. (2016)	reducing energy usage, prompting energy saving	reusage of waste materials	reduction of water consumption	prompting public transport, cycling and walking, houses built close to schools, free buses for children, subway building in plan
Low et al. (2009)	energy-efficient buildings and homes, renewable energy sources	pneumatic waste collection system	irrigation system, rainwater harvesting, water usage and leakage detection system water recycling	prompting public transport, cycling and walking
Liu et al. (2018)	prompting energy saving			
Wang & Mell (2019)	reducing energy usage, sustainable energy sources	recycling	water treatment systems	
Caprotti (2014)	energy sources, solar panels			

Jiang et al. (2009)			rainfall water collection, stormwater BMPs, controlling pollutants at the source, urban street biopods, roadside swales	
MASDAR				
Author	**Renewable energy**	**Waste management**	**Water economy**	**Transport**
Cugurullo (2013)	concentrated solar power	minimalize waste		
Reiche (2010)	switching to renewable energies, investments in the renewable energy sector			
Nader (2009)	solar power plant (CSP), evacuated thermal tube collectors, and a waste-to-energy plant	compost biodegradable materials	water recycling	no cars or internal combustion engines of any sort within the city, electrically powered transport system
Janajreh et al. (2013)	small wind turbines			
Mueller & Sgouridis (2011)				10 stations for PRT (Personal Rapid Transit), 22 stations for FRT (Freight Rapid Transit), transporting waste by electrical transport system
Yigitcanlar et al. (2019)	solar panels		movement sensors in homes to cut off access to water	an autonomous and electrified public transport system, walking and cycling network

Madichie (2011)	photovoltaics, concentrated solar power, and waste-to-energy technology	zero-waste lifestyle through reducing, reusing, recovering, and recycling waste materials	water recycling, advanced technologies to treat water, reduction of water demand	electrical transport system
Griffiths & Sovacool (2020)	photovoltaic plants on the roofs of houses		reduction in the use of interior water	PRT as a main transport system
Lee et al. (2016)	solar panels on the roofs of houses, 100 MW Concentrated Solar Power (CSP), 10 MW solar photovoltaic plant movement sensors in order to cut electricity usage		hot water produced by solar energy, movement sensors in order to cut water consumption	
El Ramahi (2017)			water desalination system	
Randeree & Ahmed (2019)		export e-waste for outsourcing recycling		public transport access, Personal Rapid Transit system combined with walking and cycling schemes
Patel & Griffiths (2013)		recovery facility, which helps recycle and compost the city's waste, used concrete goes into making roads, wood shredded and mulched	sensors to measure and analyze water usage	

Zhu et al. (2012)	rooftop mounted solar panels, wind towers and solar power plant	granulated blasted slag (an industrial waste) in place of cement, buildings built with 100% sustainably sourced timber, 100% recycled reinforcing bars, 90% recycled-content aluminum and green concrete	desalination plant generates potable water for the city	car-free zone, PRT transportation system – small self-guided vehicles pathway system for pedestrian, bicycle and low-speed electric vehicles
Tang (2010)	solar farm, energy from wind and bio-fuel sources	bio-waste composted to enrich farms and plantations, waste recycling, wastes used in a waste-to-energy plant, all steel, concrete wood recycled and reused	sea water desalination, water in separating grey and black water, recycling and using in irrigation applications	buildings with shades for pedestrians pathways
Grey (2018)	renewable technologies, solar field with 768 parabolic trough collectors	waste lifestyle through reducing, reusing, recovering and recycling waste materials	water recycling, advanced technologies to treat water	the urban transport: PRT (Personal Rapid Transit) and MRT (Material Rapid Transit), car-free zone
Hartman et al. (2012)			low-energy desalination from the selected water sources, water recycling system	LRT (Light Rail Transit) PRT as a main transportation system in the city

Source: authors' study.

Furthermore, in SSTEC packaging materials will be as far as possible reusable, recyclable and biodegradable. As it is in Masdar, Tianjin Eco-City sends a part of its waste to incinerator in another city [World Bank, 2009, pp. 89]. Masdar city provides potable water by advanced desalination system which uses solar energy as an electricity source [Zhu et al., 2012, pp. 1006]. Another water management part is recycling through advanced technologies to reuse water as many times as possible.

Every used water from sinks, showers, bath, laundry, toilets or containing harsh chemicals, will be saved, recovered and utilized to create the irrigation system [Tang, 2010]. Buildings in Masdar City are equipped with movement sensors. These sensors reduce electricity usage and water consumption [Yigitcanlar et al., 2019, pp. 5].

When it comes to Tianjin Eco-City, one of the ecological methods of water sourcing is rainwater harvesting. Because of climate indicators, this system requires to be built special collection devices, tanks and others. Project establishes two types of the system. One of them is connection of underground container with building roofs. The second one is fully placed belowground and captures stormwater [Jiank et al., 2009, pp. 10]. Used water (sewage) of various qualities will be collected and pumped into Wastewater Treatment Plant. The system consists of five pumping stations. Reclamation of the treated water from effluent and stormwater will be one of the main water supply methods in the city. Another non-conventional water source is desalination, from which the city will gain 7,900 m3 of water per day. Nevertheless, this technology covers a small part of water demand. The plant will be powered by the excess heat from Combined Heat and Power plant [World Bank, 2009, pp. 6, 65]. In SSTEC filtration and purification systems make water potable, what is important issue because water from most of Chinese cities is not safe to drink, before it is boiled [Caprotti et al., 2015, pp. 509]. Additionally, every tap and toilet in Tianjin Eco-City is planned to be ecological with flushing controlling system, which will guarantee minimal wastage [Li et al., 2018, pp. 94]. Masdar and Tianjin Eco-City use also eco-friendly transport solutions. Masdar is originally planned as a car-free zone. Vehicles with combustion engines has no enter to the city. To encourage people to moving, Masdar has pathways built specially for pedestrians and bicycles Instead of traditional cars, the transportation will be ensured by Personal Rapid Transit (PRT) system [Zhu et al., 2012, pp. 1006], which is based on autonomous vehicles. Residents are able to hire them at any time just like taxis. Typically, they seat from two to six passengers. The whole system is fully automated and includes vehicle controlling, routing and the fares collection. The technology will be not only used by passengers but also will be used to transfer freight in the city and to collect waste [Mueller and Sgouridis, 2011, pp. 2-3, 7]. One of the master's plan requirements is that nobody will be more than 250 meters away from the nearest transport facility [Randeree and Ahmed, 2019, pp. 141].

The Tianjin Eco-City encourages its residents to using public transport, which will be environmentally friendly, and to walking. Only economical cars will be able to enter the city [Caprotti et al., 2015, pp. 503]. The future target is to reach at least 90 percent of the inhabitants walking, cycling and using public transport to move in

eco-city [Low et al., 2009, pp. 375]. There are three types of public transportation in SSTEC. One of them is rail corridor, which will transit mass freight. The second one is light rail corridor which aims to connect residential areas with underground and the third kind of transport – bus network. Moreover, public facilities are linked by pathways for walking and cycling.

The ecological solutions relating renewable energy, waste management, water economy and transport in Masdar and Tianjin Eco-City are very similar (Fig. 2). Both cities are based on introduction of advanced environmental technologies – use of solar solar and wind energy, rainwater collection, desalination. Masdar City focuses on resourcing energy from Concentrated Solar Power, while in Tianjin Eco-City the sources of energy are more diversified. Both cities have adjusted systems of waste management, but additionally, SSTEC has implemented pneumatic waste-collection system. Regarding water management both Masdar and Tianjin Eco-City use desalination and water reusing programs, but only SSTEC uses rainwater harvesting. Both cities promote public transport, walking and cycling. Masdar introduced autonomic public transport and a car-free zone. Tianjin allowed for only fuel-efficient vehicles in the center and has subway building in plan.

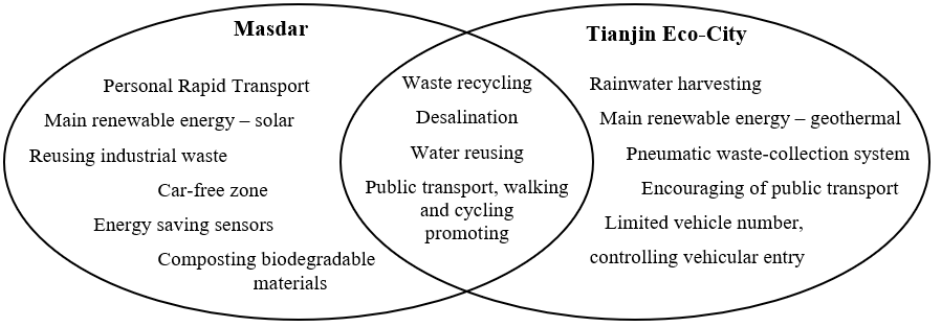

Fig. 2. Environmental technologies used in Tianjin and Masdar eco-cities

Source: authors' study.

Conclusion

The purpose of the article was to investigate the differences between ecological solutions saving energy in monsoon and arid climates on the examples of eco-cities – Tianjin Eco-City and Masdar City.

Four aspects, namely renewable energy, waste management, water economy and transport were considered. The results show that there are only slight differences between ecological solutions used in Tianjin and Masdar eco-cities.

Tianjin was created on uninhabited, highly saline and contaminated land. Masdar solves the problems of living in areas characterized by high temperatures, lack of drinking water and barren soil. The main difference is that in Tianjin City located in monsoon climate the rainwater harvesting is possible. The city location allows also for better sources of energy diversification. The Masdar energy system is mainly based on solar power.

The eco-city simply means ecological and sustainable city. The concept is based on diverse environment, economy and society ideas. The main focus is on building or transformation of the cities into places characterized by zero or low-carbon emission. The research show that the environmental technologies used in eco-cites might slightly differ. The emphasis should therefore be placed not only on different technologies used but they real impact on getting climate neutrality. Another significant issue is three-dimensional connection of technologies used with economics and society ideas. It is the only way to make eco-city be a real, living system used by humans.

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References

1. Bibri S. E. (2021), *A novel model for data-driven smart sustainable cities of the future: the institutional transformations required for balancing and advancing the three goals of sustainability*, Energy Inform 4 (4).
2. Bibri S. E. (2020), *The eco-city and its core environmental dimension of sustainability: green energy technologies and their integration with data-driven smart solutions*, Energy Informatics 3(1), pp. 1-26.
3. Bibri S. E., Krogstie J. (2020), *Smart eco-city strategies and solutions for sustainability: The cases of Royal Seaport, Stockholm, and Western Harbor, Malmö, Sweden*, Urban Science 4 (1).
4. Caprotti F. (2014), *Critical research on eco-cities? A walk through the Sino-Singapore Tianjin Eco-City, China*, Cities 36, pp. 10-17.

5. Caprotti F., Springer C., Harmer N. (2015), *'Eco'For Whom? Envisioning Eco-urbanism in the Sino-Singapore Tianjin Eco-city, China*, International Journal of Urban and Regional Research 39 (3), pp. 495-517.
6. Cugurullo F. (2013), *How to build a sandcastle: An analysis of the genesis and development of Masdar City*, Journal of urban technology 20 (1), pp. 23-37.
7. Dębkowska K., Dymek Ł., Kutwa K, Perło D., Perło D., Rogala W., Ryciuk U., Szewczuk-Stępień M.. (2022), *The Analysis of Public Funds Utilization Efficiency for Climate Neutrality in the European Union Countries*, Energies 15 (2).
8. Dioha M. O. (2020), *Nigeria's energy options in the era of climate change: an essay*, Journal of Sustainable Energy 11 (1) pp. 31-38.
9. Dziedzic S. (2015), *Ekologiczne miasta przyszłości. Masdar City-studium przypadku*, Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu 409, pp. 264-276.
10. El Ramahi M. (2017), *Case study: Masdar renewable energy water desalination program*, The Water, Energy, and Food Security Nexus in the Arab Region Springer, Cham, pp. 209-221.
11. Flynn A., Yu L., Feindt P., Chen, C. (2016), *Eco-cities, governance and sustainable lifestyles: The case of the Sino-Singapore Tianjin Eco-City*, Habitat International 53, pp. 78-86
12. Grey F. A. (2018), *Masdar City as a Prototype for Eco-Cities*, Digest of Middle East Studies 27 (2), pp. 261-277.
13. Griffiths S., & Sovacool B. K. (2020), *Rethinking the future low-carbon city: Carbon neutrality, green design, and sustainability tensions in the making of Masdar City*, Energy Research & Social Science 62.
14. Gürel Ulusan N. (2017), *The guidelines of the eco-city based on sustainable urbanism.* International sustainable buildings symposium, Springer, Cham, pp. 871-879.
15. Hartman M. M., Kulaib A. A., Drew C. R., Witherspoon J. R. (2009), *Water Challenges in Building a Sustainable City in the Middle East-A Masdar Perspective*, Water Practice and Technology 4 (4).
16. Hu M. C., Wu C. Y., Shih T. (2015), *Creating a new socio-technical regime in China: Evidence from the Sino-Singapore Tianjin Eco-City*, Futures 70, pp.1-12.
17. Huovila A., Siikavirta H., Rozado C., Rökman J., Tuominen P., Paiho S., Hedman A., Ylén P. (2022), *Carbon-neutral cities: Critical review of theory and practice*, Journal of Cleaner Production 341.
18. Jabareen Y. R. (2006), *Sustainable urban forms: Their typologies, models, and concepts*, Journal of planning education and research 26 (1), pp. 38-52.
19. Janajreh I., Su L., Alan F. (2013), *Wind energy assessment: Masdar City case study*, Renewable energy 52, pp. 8-15.

20. Ji Z. M., Shen M. (2014), *Research on Path of the Construction of Ecological City Under Polycentric Governance-Taking Tianjin Eco-city as an Example*, Proceedings of 2013 4th International Asia Conference on Industrial Engineering and Management Innovation (IEMI2013), Springer, Berlin, Heidelberg, pp. 947-956.
21. Jiang M., Lin X., Asselin S. (2009), *Exploration of Integrating Stormwater Best Management Practices into Landscape Design in Sino-Singapore Tianjin Eco-City*, Water Practice and Technology 4 (4).
22. Joss S. (2011), *Eco-cities: the mainstreaming of urban sustainability - key characteristics and driving factors*, International Journal of Sustainable Development and Planning 6 (3), pp. 268-285.
23. Joss S., Molella A. P. (2013), *The eco-city as urban technology: Perspectives on Caofeidian international eco-city (China)*, Journal of Urban Technology 20 (1), pp. 115-137.
24. Joss S., Tomozeiu D., Cowley R. (2012), *Eco-city Indicators: Governance Challenges*, WIT Transactions on Ecology and the Environment 155, pp. 109 - 120.
25. Kenworthy J. R. (2006), *The eco-city: ten key transport and planning dimensions for sustainable city development*, Environment and Urbanization 18 (1), pp. 67-85.
26. Khalid Z., Abaas Z. R. (2021), *Defining the aspects of the local urban sustainability: Eco-cities as a model*, IOP Conference Series: Earth and Environmental Science 754.
27. Lee S. E., Braithwaite P., Leach J. M., Rogers C. D. (2016), *A comparison of energy systems in Birmingham, UK, with Masdar City, an embryonic city in Abu Dhabi Emirate*, Renewable and Sustainable Energy Reviews 65, pp. 1299-1309.
28. Li Y., Bonhomme C., Deroubaix J. F. (2018), *Can a Sustainable Urban Development Model be Exported? Construction of the "Exemplary" Tianjin Eco-city*, China Perspectives 1-2, pp. 87-97.
29. Liu Y., Hong Z., Shi X. (2018), *Antecedents of residents' repurchase intention of green residential building: case study of Sino-Singapore Tianjin ecocity*, Energy Procedia 152, pp. 366-371.
30. Low S. P., Liu J. Y., Wu P. (2009), *Sustainable facilities: institutional compliance and the Sino-Singapore Tianjin Eco-city Project*, Facilities.
31. Madichie N. O. (2011), *IRENA-Masdar City (UAE) - exemplars of innovation into emerging markets*, Foresight 13 (6).
32. Masdar a Mubadala Company, https://masdar.ae/en/masdar-clean-energy/technologies/wind [09.11.2022]
33. Mezher T., Tabbara S., Al-Hosany N. (2010), *An overview of CSR in the renewable energy sector: Examples from the Masdar Initiative in Abu Dhabi*, Management of Environmental Quality: An International Journal 21 (6), pp.744-760.

34. Mueller K., Sgouridis S. P. (2011), *Simulation-based analysis of personal rapid transit systems: service and energy performance assessment of the Masdar City PRT case*, Journal of advanced transportation 45 (4), pp. 252-270.
35. Nader S. (2009), *Paths to a low-carbon economy—The Masdar example*, Energy Procedia 1 (1), pp. 3951-3958.
36. Octavian C., Silviu D. (2018), *About large integration of small residential photovoltaic energy cells into SEN*, Journal of Sustainable Energy 9 (2), pp. 87-92.
37. Okoli C. (2015), *A Guide to Conducting a Standalone Systematic Literature Review*, Communications of the Association for Information Systems 37, pp. 879-910.
38. Panait A. (2017), *The capacity of bioliquids extracted from oil-rich-plants to be renewable energy sources in Romania*, Journal of Sustainable Energy 8 (2), pp. 60-65.
39. Paris Agreement, Journal of Laws (EU L 282/4, 16.10.2016).
40. Patel P., Griffiths S. (2013), *Masdar City showcases sustainability*, MRS Bulletin 38 (6), pp. 450-451.
41. Piotrowicz W.D., Ryciuk U. , Szymczak M. (2021), *Lean and agile metrics. Literature review and framework for measuring leagile supply chain*, International Journal of Productivity and Performance Management.
42. Randeree K., Ahmed N. (2019), *The social imperative in sustainable urban development*, Smart and Sustainable Built Environment 8 (2), pp. 138-149.
43. Szpilko D., Ejdys J. (2022), *European Green Deal — research directions. A systematic literature review*, Ekonomia i Środowisko, 81, p. 8-38.
44. Szpilko D., Szydło J., Winkowska J. (2019), *"Smart" or "Wise" City? A New Approach to City Management*, CID Conference 2019: International Scientific Conference on Collaborative Innovation Development: Book of Abstract, s. 214-219.
45. Register R. (1987), *Ecocity Berkeley: Building Cities for a Healthy Future*, North Atlantic Books: Berkeley, CA.
46. Tang G. (2010), *Masdar-The Sustainable Desert City: A Theoretical Mirage or A Realistic*, CSAAR Press, The Center for the Study of Architecture in the Arab Region, pp. 175-189.
47. Tao Z., Zhengnan Z. (2013), *Urban surface water system in coastal areas: A comparative study between Almere and Tianjin Eco-city*, Open Journal of Ecology.
48. Tourani A., Jamshidi A. (2016), *The role of structure novelty of sustainable urban form in energetic cities (case studies of Masdar and Bushehr cities)*, Turkish Online Journal of Design Art and Communication 6, pp. 3118-3130.
49. Wang X., Mell I. (2019), *Evaluating the challenges of eco-city development in China: a comparison of Tianjin and Dongtan eco-cities*, International Development Planning Review 41 (2), pp. 215-242.

50. Wong T.C., Yuen B. (2011), *Eco-city planning*, Policies, practice and design: Springer Science+ Business Media BV.
51. World Bank (2009), *Sino-Singapore Tianjin eco-city: A case study of an emerging eco-city in China*, World Bank.
52. Wu Y., Swain R.E., Jiang N., Qiao M., Wang H., Bai J., & Wu J. Z. (2020), *Design with nature and eco-city design*, Ecosystem Health and Sustainability 6 (1).
53. Yang W., Deng W. (2013), *Building related kpis in Sino-Singapore Tianjin eco-city*, APCBEE Procedia 5, pp.112-115.
54. Yee T. W., Lawson C. R., Wang Z. Y., Ding L., Liu Y. (2012), *Geotextile tube dewatering of contaminated sediments, Tianjin Eco-City, China*, Geotextiles and Geomembranes 31, pp. 39-50.
55. Yigitcanlar T., Han H., Kamruzzaman M., Ioppolo G., Sabatini-Marques J. (2019), *The making of smart cities: Are Songdo, Masdar, Amsterdam, San Francisco and Brisbane the best we could build?*, Land Use Policy 88.
56. Zhan C., De Jong M., De Bruijn H. (2018), *Funding Sustainable Cities: A Comparative Study of Sino-Singapore Tianjin Eco-City and Shenzhen International Low-Carbon City*, Sustainability 10.
57. Zhang T. Y., Jin Y. P. (2010), *Urban Agricultural Development from the Perspective of Circular Economy-An Analysis of Sino-Singapore Eco-city Model in Tianjin*, Asian Agricultural Research 2, pp. 9-12.
58. Zhu D., Kung M., Whiteford B., Boswell-Ebersole A. (2012), *Analysis of sustainable materials used in ecovillages: Review of progress in BedZED and Masdar city*, Journal of Wuhan University of Technology-Mater. Sci. Ed. 27 (5), pp. 1004-1007.
59. Zou X., Li Y. (2014), *How Eco are China's Eco-Cities? An International Perspective*, International Review for Spatial Planning and Sustainable Development 2 (3), pp. 18-30.

Dążenie do neutralności klimatycznej – technologie środowiskowe stosowane w eko-miastach na przykładzie Tianjin Eco-City i Masdar

Streszczenie

Celem artykułu jest zbadanie różnic pomiędzy ekologicznymi rozwiązaniami oszczędzającymi energię stosowanymi w eko-miastach na przykładzie Tianjin Eco-City i Masdar City. Artykuł oparty jest na systematycznym przeglądzie literatury. Zebrano literaturę, po czym

naświetlono tło powstania obu miast oraz ich lokalizację. Następnie autorzy porównali oba miasta pod względem zastosowanych w nich technologii środowiskowych. Pod uwagę wzięto cztery aspekty, a mianowicie energię odnawialną, gospodarkę odpadami, gospodarkę wodną oraz transport.

Słowa kluczowe

eko-miasto, neutralność klimatyczna, rozwiązania ekologiczne, Sino-Singapore Tianjin Eco-City, Masdar City