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# Creating Global Sustainable Smart Cities (A Case Study of Masdar City)

Venkatanarayanan Sankaran and Ashok Chopra

Amity University, Dubai

**E-Mail:** vsankaran@amityuniversity.ae, achopra@amityuniversity.ae

**Abstract:** Many of the global cities are fast developing into resource-starved ecosystems, inefficient, unmanageable and unsustainable, owing to rising population and industrialization, adversely affecting the economic growth and quality of life, health and well-being of the communities inhabiting these cities. Furthermore, because of increasing urbanization, on the one hand, these cities are grappling with day-to-day challenges of risk and security concerns related to economic, technological and social development; and, on the other hand, they are also battling with environmental challenges related to energy, its source and insufficient availability, given that conventional energy sources such as fossil fuels are fast depleting and at the same time energy requirements to drive the physical infrastructure and economic engine of these already over-populated cities are rapidly escalating – not to mention the environmental threats posed by these traditional finite energy sources notoriously known for their carbon and other greenhouse gas emissions. Abu Dhabi, one of the emirates of the United Arab Emirates, launched The Masdar City which is presently underway and being built in Abu Dhabi by the subsidiary unit of the state-owned Mubadala Development Company. (Halligan, Neil, 2019)<sup>1</sup> This paper delves into the details of Masdar City which is unique and unconventional in many ways as it embraced information and communication technologies (ICT), more visibly Internet of Things (IoT), for better quality of life and performance of services, for an ecologically-balanced integrated urban development thereby becoming a ‘Smart City’. The city further leveraged this smartness in a domain convergent with ‘Sustainability’ with technology-driven goals related to eco-friendly environment, self-generated energy availability through solar, energy efficiency and other zero-carbon features in subsystems such as transportation, civic utilities, physical infrastructure, water management, waste management and so on. Additionally, this conceptual paper reviews the case of other similar global cities and explores how Masdar can position itself as a sustainable, smart city for others to follow

**Keywords:** Masdar Smart City, Internet of Things, Sustainability, Environment, Renewable Energy, Eco-city, Smart Cities, Self- Sustainable Cities, Global Sustainable Smart Cities

## 1. INTRODUCTION

The United Arab Emirates (UAE) has grown in many sectors of the economy that includes banking, logistics, management etc. Its capital city, Abu Dhabi transformed from a land of fewer people to a modern wealthy city with more than a million people living in the city. Among all the other six emirates of UAE, Abu Dhabi is the largest emirate of the UAE and it, also has the largest reservoir of the nation’s fuels. It was really, important to initiate a project as ‘Masdar’ in the UAE, as it has the poorest footprint of carbon among the other countries. The fundamental goal behind this project was to reduce water, electricity and overall energy usage in the city by diverting focus towards concentrated solar collectors, rooftop photovoltaic panels, geothermal resources etc. Even water in the city is recycled with by-products finding use as energy that is, transformed through a gasification



process, which is then used for construction and other purposes. In addition, Masdar used intelligent/smart technological designs and traditional Arab style designs too for achieving minimum energy and material usage. (Ouroussoff N2010)<sup>2</sup> To ensure focus towards the objectives of carbon efficiency, Abu Dhabi's Urban Planning Council built up the Pearl Rating System, instituted to assess the buildings for adherence to designs and structures. Masdar institute has been recognized as the world's first institute to be dedicated to sustainability and renewable technologies.

Increasing urbanization is another phenomenon the world is witnessing in view of industrialization, livelihood opportunities and other factors. People are migrating from rural backyards to urban areas at an accelerated pace and it is anticipated that 70% of the world's population will be living in urban spaces and cities by 2050 (Goldstone J.A., 2010)<sup>3</sup> potentially resulting in a scenario of crumbling physical infrastructure, inadequate social and health services, insufficient security systems, unpredictable human interrelationships and higher levels of competition and complexity besides the escalating demand for energy resources; and, hence the significance of commissioning smart, sustainable city projects around the world like Masdar City which, on completion, would have a balanced ecosystem instituted through a two-pronged, mutually reinforcing strategy of smart ICT technologies adoption on the one hand and smart energy generation, conservation and management techniques on the other side.

## 2.0 RESEARCH OBJECTIVE

The topic being a fast-evolving one, in the background of a multitude of questions voiced by proponents and critics, such as – are smart cities really needed for economic resilience and development; what social implications smart cities will have to encounter from the 'human-benefits' angle - in terms of interconnectedness and quality of life and well-being; will smart cities achieve energy resource self-sufficiency for urban development needs; will the chosen alternative energy source sufficiently address environmental concerns; what mix of smart technologies will be adequate for sustainable urbanism and other related questions, this conceptual, descriptive paper, derived from an extensive literature review, attempts to explore the smart and eco-city developmental initiatives and features of Masdar City against the backdrop of other similar global cities. This paper also offers a general framework of analysis from an understanding of how Masdar can possibly transform itself into a world leader as a smart, sustainable city.

## 3.0 METHODOLOGY

The methodology largely depended on major contributions coming from scholarly literature as part of secondary data. It involved identification, elimination and practical screening of relevant publications and articles. The keywords were so chosen and used to cover topics of research focus like Masdar, smart city, sustainability, eco-city, renewable energy, globally sustainable cities, renewable technology, zero carbon, waste management, water management and transportation management for a systematic literature search, review and further analysis.

## 4.0 MAIN ANALYSIS (THE CASE OF MASDAR):

### 4.1 A Sustainable City

Masdar, understood as 'Source' in Arabic, encapsulates the idea of a clear vision of the city. The city, powered solely by renewable energy, focuses on environmental sustainability by optimizing the use of natural resources. The city demonstrates Abu Dhabi's commitment to an environment-friendly system by developing a powerhouse for renewable energy technologies and innovation from concept through to fruition. The city's 10MW solar power array and 1MW rooftop-type solar panels and wind related technologies for power generation can cater to a target population of 40,000 in the city. Besides, in the light of Abu Dhabi echoing commitments similar to that of Dubai Government to replace 75% of its requirement of electricity with clean and alternative energy by the year 2050, Masdar will play a very significant role

#### 4.2 Sources of Energy in Masdar City

Masdar is intended to be One hundred percent fueled by sustainable power source, while 170 MW (53%) of the all - out power used is given by Photo Voltaic. (Refer figure 1) The energy utilization in Masdar City should be under 30 KWh per capita every day, a sum which is multiple times much less than the per capita power in use in USA.

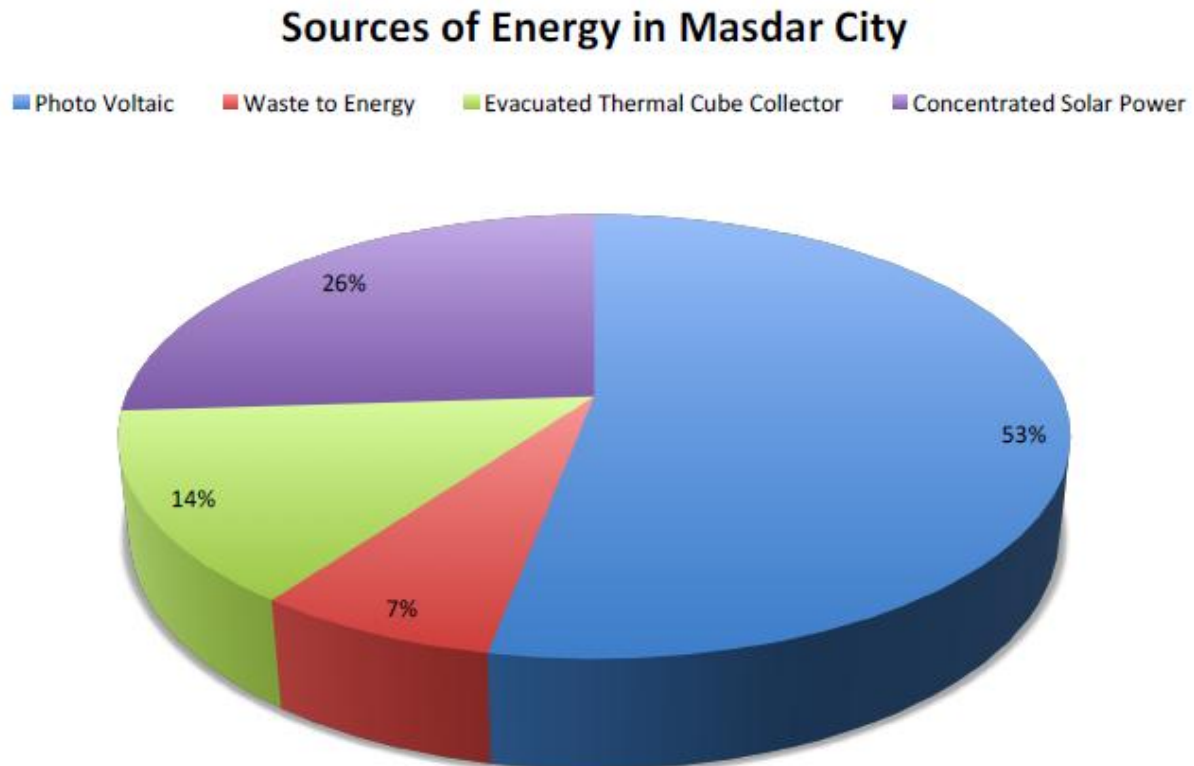
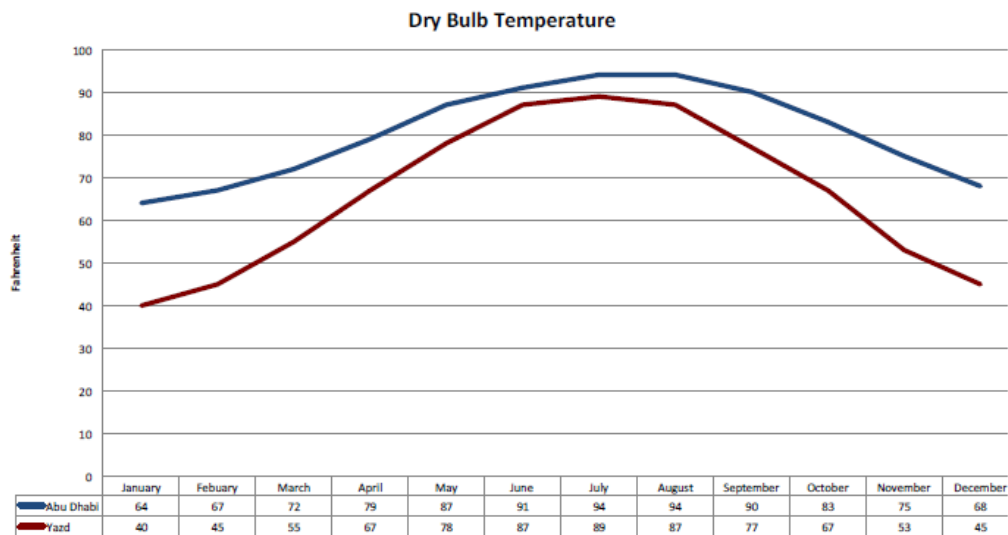


Figure 1: Sources of Energy in Masdar City  
Photo Voltaic (Shams 1 Power Project) provides more than half of the energy of Masdar

#### 4.3 Site Climatic Context Data availability and sources

For the purpose of climate analysis (Refer figure 2) and thermal simulation, data is, taken from the U.S. Department Energy Database, collected from 412170 (IWEC) Abu Dhabi International Airport and 408210 (ITMY) Yazd International Airport WMO Stations. Unfortunately, the nearest weather report station to Masdar City is the Abu Dhabi international airport, which is 6 miles away from the Masdar City boundary.

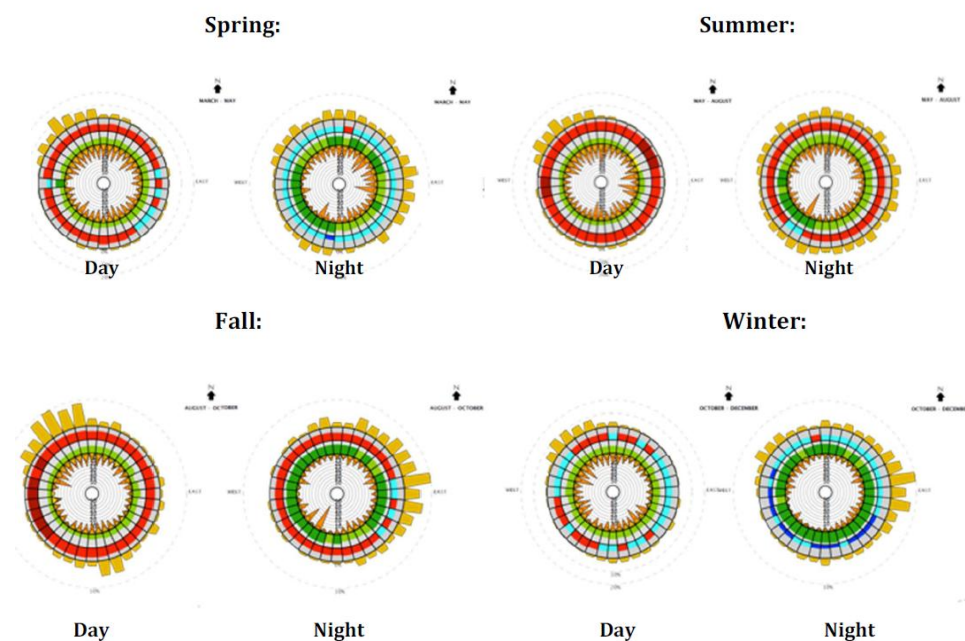
The files, which the Adaptive Comfort Model in ASHRAE Standard 55-2010 was used in order to generate design conditions, are listed below:



**Figure 2.** Comparison between the dry temperature of Yazd and Masdar City

#### 4.4 Wind Pattern Supporting Energy Management at Masdar:

Masdar has distinct seasonal and daily patterns in wind (figure 3). Generally from around 8am through to 8pm, when land heats up during the day more quickly than water (Energy Design Resources by Architectural Energy Corporation, Boulder, CO), there is a dry air rising from the north west bringing dusty air from the desert to the interior south with typical wind speeds of c. 2.5m/s [pha consult, 2008]. At the night, the wind turns, rising through east to north-northwest carrying a cooler, due to the loss of the radiation in night and more humid air -rom over the Persian Gulf at higher speeds – typically 4.2m/s (pha consult, 2008)<sup>22</sup>



**Figure 3:** Distinct Seasonal and Daily Patterns in Wind in Masdar City

As of today there are entities that not only own the process but also control the transactions as intermediaries causing delay and financial losses to transacting parties in the form of fees and charges, and thus making transactions unnecessarily expensive.



#### 4.5 Energy Management in Masdar

The city being in the middle of a desert posed the most formidable challenge because of the extremely hot climatic conditions for most part of the year. Right from the planning perspective itself, as reported by N. Ouroussoff in New York Times, Masdar City was built on a 23-feet tall concrete base for it to have maximum exposure to cool winds to reduce air conditioning needs. (Ouroussoff N, 2010)<sup>2</sup> To understand sustainability at Masdar in detail, therefore, transportation, water management, waste management and other energy related subsystems were reviewed for this paper.

A two-fold Energy Management approach was conceptualized for Masdar City: (i) Reduced energy consumption by using globally proven energy-efficient techniques – natural light, insulation, window-glazing, low-energy specifications for lighting, smart building systems and appliances. (What is Masdar City 2011)<sup>4</sup>; and, (ii) Efficient energy generation using novel techniques – innovatively re-designed Photovoltaic (PV) panels for solar energy (Myllylä S and Kuvaja K 2005)<sup>5</sup> – The Beam-Down Solar project (figure 4 &5), a joint work of the Masdar Institute, Japan's Cosmo Oil Company and the Tokyo Institute of Technology. Unlike the Concentrating Solar Power technique, used traditionally, where mirrors reflect sunrays to a receiver placed atop a central tower which then heats up a heat-transfer fluid to generate steam for a steam turbine; in the new design, the receiver is placed at the base of the tower thereby eliminating loss of energy in the process of pumping the liquid to the receiver when placed at the top. This reportedly is the largest grid-connected solar plant in the Middle East providing clean energy to several sites, offices and construction activities in Masdar City. (Myllylä S and Kuvaja K 2005)<sup>5</sup>

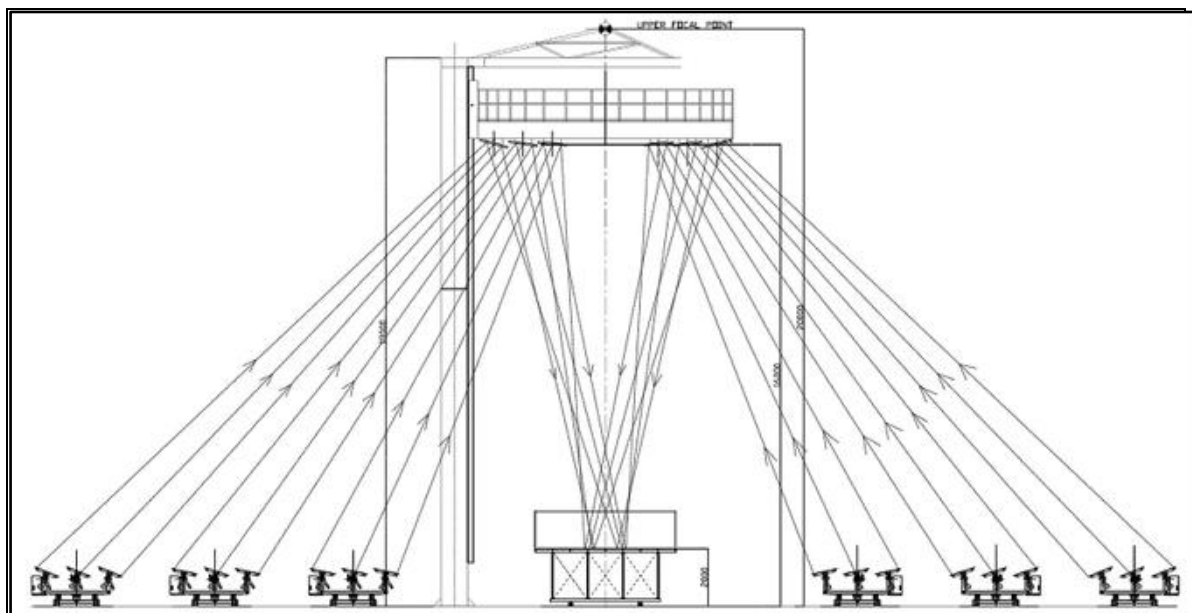


Figure. 4. Beam-Down Solar Collector



Figure 5 Masdar's Beam-Down Solar Plant

#### *4.6 Transportation in Masdar*

At the conception stage itself, with a single-minded focus on clean and efficient energy, the city's plan was to replace gasoline-fueled vehicles with automated electric cars that would navigate through an intricate network of tunnels below the concrete base on which Masdar City was raised. (Ouroussoff N, 2010)<sup>2</sup>

The transportation system in Masdar city is designed around convenience, efficiency and safety of its residents. Being low carbon emission city with reduced water and power consumption, it aims to maintain the same low levels with transportation vehicles as well. As a step towards emitting less vehicular carbon, Masdar avoids petrol-driven vehicles. Masdar will officially be the first car-free city in the world. The city will be linked to major location(s) in Abu Dhabi through Light Rail Transit System (LRT), a carbon-free vehicle powered by electricity. The vehicles will accommodate up to six people and will run on recyclable lithium cadmium battery. While the city acknowledges the convenience offered by private transport, it also ensures the same is, provided in a more environment-friendly format.

#### *4.7 Water Management in Masdar*

With the long term objective of reducing per capita domestic water consumption, Masdar City targeted along two fronts: (i) Reduce water wastage by promoting use of efficient and smart appliances (showers, laundry systems, and water meters), incentivized and informed water tariffs and efficient landscaping and crop irrigation (Myllylä S and Kuvaja K 2205)<sup>5</sup>; and, (ii) Improve efficiency of wastewater treatment and processing methods.

The entire water used in the city is desalinated and made suitable for drinking purposes using solar energy. As availability of adequate water remains an inherent challenge when it comes to initiating any construction activity in desert areas, the city reuses the desalinated water for many other purposes. Wastewater treatment is, done using a Membrane Bioreactor (MBR Refer figure 6) process that uses a suspended sludge system of microporous membranes that separates the solid from the liquid in the

combined grey and black water mix. (Figure 3) The treated effluent finds use in landscaping and bio-solids in irrigation and composting

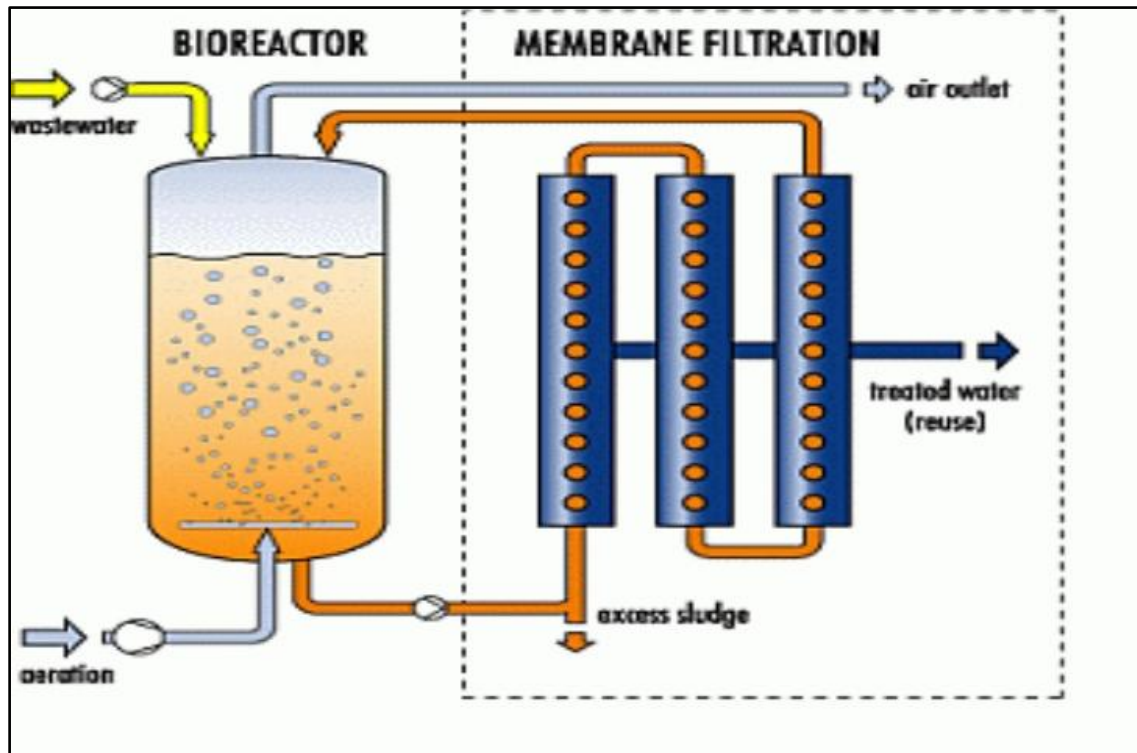


Figure 6: Membrane Bioreactor Technology for Wastewater

#### 4.8 Waste Management in Masdar

For waste management, vacuum technologies are used to eliminate the need for landfill. Waste is, accordingly segregated prior to collection and disposal. While part of the city's waste is recycled, in other cases an electricity-generating process incinerates the waste, which leads to release of much less carbon dioxide compared to landfill. (Ouroussoff N, 2010)<sup>2</sup>(Fortson D 2009)<sup>6</sup> Bio-waste is composted and the end-product is used to improve farms located in the outskirts of the city. Recyclable waste is, reused and the remaining waste is, utilized in a waste-to-energy plant.

#### 4.9 Masdar - An 'Internet of Things' Modelled Smart City

While no standard definition universally exists for 'smart cities' as it assumes various dimensions, the term is synonymously used as digital cities, intelligent cities, wired cities and so on. The International Telecommunication Union (ITU), however, regards smart sustainable city as one that uses a blend of information and communication technologies (ICTs) for improved quality of living, efficient operations and services in urban space and at the same time not compromising on the needs and expectations of the present day or future generations from the viewpoint of economic, environmental and social development. (Smart sustainable cities - The Official Portal of the UAE Government).<sup>7</sup> One can, therefore, infer that a smart city must live up to many aspects of urban living such as quality of life, intelligent transportation, automated public utilities (gas, power and water), smart airports, smart buildings, smart universities, smart healthcare, smart waste management, smart security, safety and hygiene and all ecologically balanced. (In smart cities, for example, cars will flash messages automatically regarding traffic congestion, homes will regulate temperature and lighting automatically, hospitals will remotely control medical equipment and factories will automatically detect machine problems and fix them.) Frost and Sullivan referred to a comprehensive set of concepts/essentials for a city to be considered 'smart' as in figure 7. (Vadgama C.V., Khutwad A., Damle M., Patil S 2015)<sup>8</sup> (Ashok Chopra, Venkat Sankaran).<sup>21</sup>



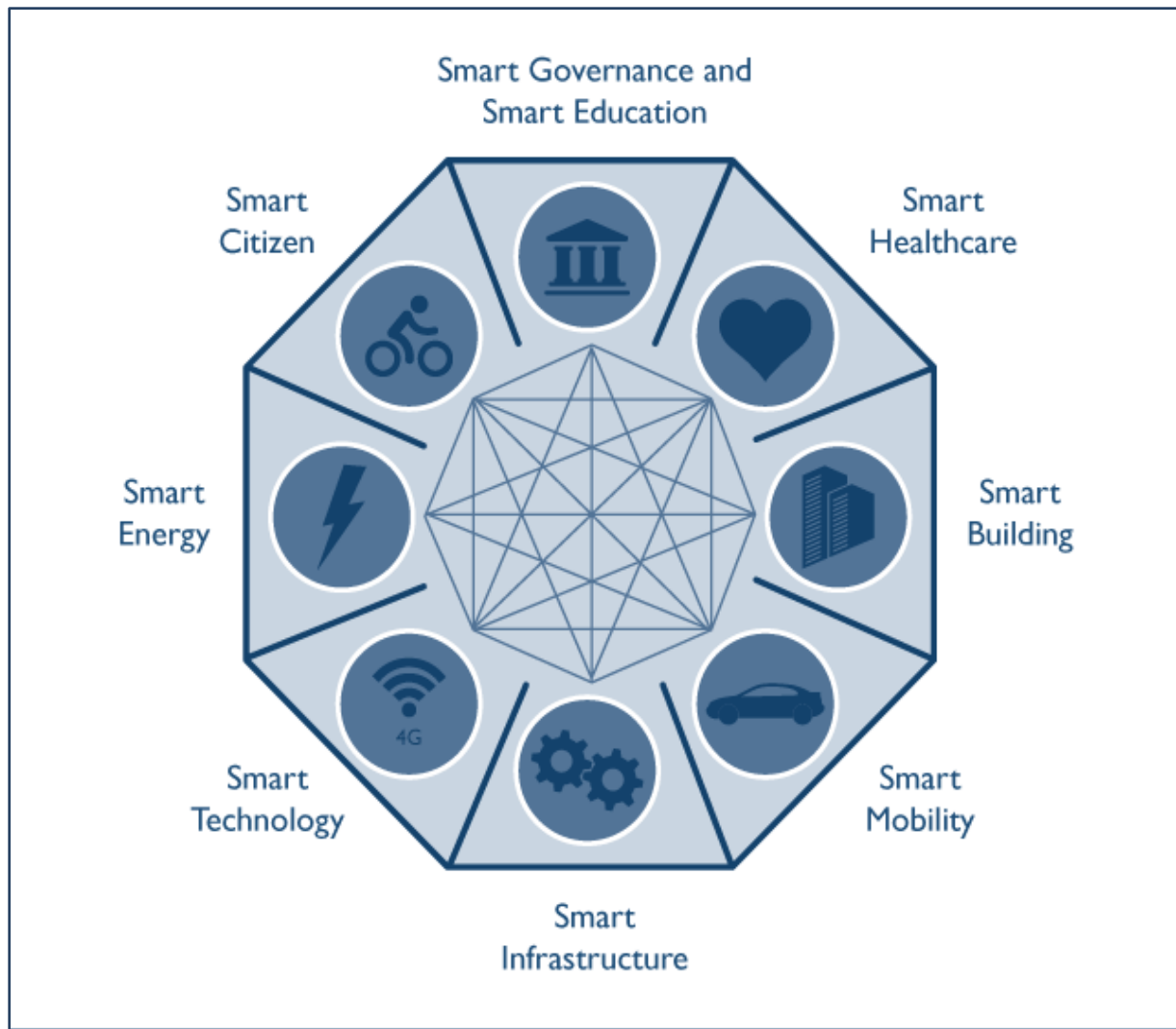


Figure 7: Smart City Concepts

“Smartness” along these concepts in smart cities is achieved by deploying appropriate information, communication and computing technologies in every conceivable walk of life, personal and commercial. Completely automated IoT is an important and pervasive technological solution in this respect and essentially depends on the functioning of an integrated set of many varied devices connected to the internet using different networking protocols. Chun BT, 2015)<sup>9</sup> (Maninder Jeet Kaur, and Piyush Maheshwari 2016)<sup>10</sup>

IoT involves an integrated mix of actuators, sensors, RFID (Radio Frequency Identification) with a communicational interface and computational capability, all supported by the internet. Internet-based protocols such as IPv6, HTTP and UDP/TCP facilitate accessibility and communication to daily-use electronic appliances such as washing machine, refrigerator, heater etc. via internet. (Maninder Jeet Kaur, and Piyush Maheshwari 2016)<sup>10</sup> Other internet protocols that are proposed for resource-constrained devices are 6LowPAN, RPL and CoAP and also gateways / non internet protocols like Z-wave, ZigBee and HART are used for communicability so much so that even non-electronic ‘things’ (which are normally inconceivable in IoT parlance) such as clothing, furniture, food, mechanical parts and miscellany of culture, commerce and sophistication can potentially come in the ambit of IoT connectivity. Kosmatos EA, Tselikas ND, Boucouvalas AC 2011)<sup>11</sup>

#### 4.10 Smart Urban Planning

In Masdar City, GPS and GIS technologies have been at the forefront to, effectively align transport planning with land use - A wall around the city or green zones or high building densities around Public Transport (PT) stations. The city focuses on the extensive use of GIS in every aspect of the city plan whether it be for efficient construction processes, for effective monitoring systems in the city's infrastructure or for energy and transportation network.

#### 4.11 Smart Buildings and Offices

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The new headquarters of Siemens Middle East in Masdar City is a building with automatically adjusting temperature and lighting system and automatic security, fire alarm and gas suppression systems coming from Siemens Building Technologies in line with the most advanced global technologies and will house about 800 employees for best comforts. (Siemens, 2015)<sup>12</sup>

The global headquarters of International Renewable Energy Agency (IRENA) is based in Masdar Smart City (IRENA 2015)<sup>13</sup> and is a smart and environmentally sustainable construction owing to its innovative design and deployment of IoT technology for all its benefits. (Ashok Chopra, Venkat Sankaran)<sup>21</sup>

#### 4.12 Smart Transportation

Masdar City aims to have its streets free from automobiles and instead have a Personal Rapid Transport (PRT) system of smart transportation featuring a network of electric automatic taxis. Such smart city transit technologies will use these driverless compact "Podcars" (as in figure 8) to offer clean, convenient and quiet means of transportation to the city's residents paving the way for a more sustainable mobility sector



Figure 8: Personal Rapid Transport System

#### 4.13 Smart Home Farming

Baas In its commitment to embrace smart technology, it recently showcased ‘Bustani’ in its Masdar City eco-villa, to demonstrate innovative and smart home farming solutions centered around production of food and recycling of waste and water. Jointly conceived by agro-tech specialists, Madar Farms and Masdar, this concept demonstrates how villa-residents can produce food in their own premises using IoT technologies thereby highlighting the significance of smart farming technologies in promoting self-sufficiency and food security at home and the possibilities of scaling it up to the national and global level considering the challenges today’s food systems face in sustainably feeding the increasing global population. (Gulf News).<sup>14</sup>

### 5.0 LESSONS LEARNED FROM SIMILAR GLOBAL CITIES ELSEWHERE

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There are several other cities in the world that have focused on sustainability and eco-friendly environment. This paper looks at some of the best such cities to see whether Masdar can replicate its model in some of the related fields towards becoming the best.

Copenhagen, Denmark is a city of bikes and a large section of its residents use their bikes as a primary means of transportation. Copenhagen’s biking culture is just one of the many characteristics that makes the city green and sustainable. The goal of the city is to become the world’s first carbon neutral capital by 2025. Another aim of the city is to bring its carbon dioxide consumption from its present level of around 2.5 million tons to under 1.2 million tons in another two decades. The notable features of this city that makes it a green city are green roofs, bike city, electric buses and, electric public transport, green areas, clean tap water and ocean quay. (Copenhagen: A Sustainable City).<sup>15</sup> One of the biggest concentrated solar plants in the world is located in the heart of Morocco, Ouarzazate. It involves five different projects, which is spread over 10,000 hectares and is likely to be completed by 2020. Moreover, Morocco has restricted the use of plastic bags and has launched new ideas for extending the networks in Casablanca and Rabat. Lately Morocco is also trying to invest in wind. ([Principles of Urban Sustainability]).<sup>16</sup> Stockholm, in Sweden, is the first city to be designated as European Green Capital by the EU Commission in 2010. Instead of building new homes for the people, this city redevelops old industry area with efficient low energy housing system. The only reason for the city to get awarded was the guarantee of the environmental factors and aspects which are considered in budgets or monitoring etc. In other words, whatever happens in the city of Stockholm, it has sustainability at its core. It is already an eco-friendly city as the city has underground pipes connected to all the buildings in the city which takes away the waste in the form of hot water which can then be easily added to in the network. ([Stockholm – leading the way in sustainability]).<sup>17</sup> Munich, a city in Germany, aims to have clean energy by 2025. The city has already invested 9 billion Euros to produce clean energy projects such as the hydro power plant which is meant to be along with the river around the whole city. The city of Munich already owns a utility association which has already invested in wind projects. Moreover, the goal of promoting sustainable energy has already pushed Munich’s energy sector in expanding infrastructure. (Munich - A Green and Sustainable City.)<sup>18</sup> Singapore is one of the world’s largest commercial centers. Factors that led Singapore surge ahead as a global leader in sustainable city are regulations, consumer education and awareness. The policies of Singapore are, designed to promote sustainability and economic growth. Singapore has also been successful in its approach in developing solutions for every environmental goal. Owing to its success, Singapore’s clean and green image has always been a marketing tool for attracting international companies and investments. Singapore uses real-time data from mobile phones to improve public transportation from an analysis to understand the time of the day when people most use public transport. Several innovative apps also help taxi drivers to reach the rainiest areas of the city based on weather forecasts available 10 minutes prior. (Peter King, Sustainable City Singapore)<sup>19</sup> Amsterdam, the capital of Netherlands, is a city with its operating systems integrated at

one point. Several apps operate in the background of large public data opened up – ‘Appening Amsterdam’ to choose a place for night out; ‘Bike a Local’ for tourists to cycle in the city; ‘Drive Carefully’ that motorists use while driving in the vicinity of a school. The website of Amsterdam Smart City includes very interesting schemes including a platform for friends and neighbors to safely share their cars in a sustainable neighborhood where 500+ homes are equipped with smart meters to inform the residents of their consumption of energy. (Tomorrow’s cities: Do you want to live in a smart city).<sup>20</sup> Dubai, adjacent to Abu Dhabi in the UAE and one of the most modern and sophisticated cities in the world with some of the world’s tallest and largest structures built here, launched its ‘Smart Dubai’ strategy in 2014. Being one of the foremost tourist destinations of the world, smart tourism app through smart phones that allows travelers to access tourist information anytime, from anywhere is one of the smartest smart initiatives introduced here.

## 6.0 DISCUSSION

Growing urbanization is resulting in increased complexity of lifestyles, deterioration of quality of life and dearth of conventional energy resources. At the same time, with meteoric rise in the usage of smart devices to be connected to the internet, life would be more comfortable with many IoT based technologies in future. This implies the need for huge electric energy or, alternatively, demand for low-power consumption solutions. In this context, Masdar, as a sustainable smart city, can be considered to be a standing example for deploying natural energy resources while constructing smart buildings and other infrastructure while simultaneously reducing consumption of energy. Masdar has built buildings with less cement and other fabrications to keep the interior of the buildings less warm and to keep it cooler throughout the day. The buildings are, built in such a way that it consumes 40% less water and energy than the other conventional buildings in Abu Dhabi. By working on this project, the only goal of the founders of Masdar City is to earn the title of ‘Transition from a 20th century carbon economy to 21st century sustainable economy’ as it can provide a blue print to all future cities striving for sustainability

With regard to energy issues related to transportation, Masdar has smartly planned to have a combination of clean energy vehicles, PRT system and electronic cars and parking arrangements for private cars are limited to the city’s boundaries. The city is solely, resourced by natural sources like solar energy. As a regional center for development and utilization of cleaner technologies, Masdar Smart City has demonstrated and commercialized the proof of concept with its smart grid technology, ZigBee technology, radically new urban designs of construction and green buildings.

As for economic diversification as one of its motives for eco- and smart city development, Abu Dhabi plans to use this project to encourage private entrepreneurship and generate economic activities in fields other than the oil sector. As for sustainability and technology, it also is actionable through urban diversification that has a positive impact on the reduction of energy usage, particularly in hot humid climates found in Abu Dhabi. A better example of this urban agglomeration is where, tall buildings with digital benefits and closer proximity of activities can be combined for professional and personal life.

Issues regarding social cohesion do exist in the UAE, with a lot being, published with regard to relationship ties between the minor general population and labor that forms the majority in the country. Value changes and public participation are other considerations to be thought of inside Masdar. Indeed, balancing such variables would be at the heart of the eco-city design whether framed in favor of planet, people or profit. And to achieve this, Masdar should be standing out as an eco-city striving to encourage and include the society of UAE. It is through such social networking and relationships that the environment of Masdar City can succeed if it wishes to adapt to the approach of sustainable development encompassing also the social dimensions.

Having reviewed the other similar cities in the world and their striking features, we realize that they are all different in their own ways. They have all employed leading technology firms such as IBM, Intel, Microsoft, Cisco, and Siemens for software solutions to a variety of problems these cities face. But, Masdar, being the most systematically and holistically built, it has been appreciated for its unique and all-inclusive unique way of tying up economic, technological, sustainable and social facets

comprehensively in its ecosystem

## 7.0 CONCLUSION

The primary intent of building sustainable smart cities is to achieve and preserve an ecologically balanced system. Maximum generation and utilization of solar, tidal, wind and geothermal sources as natural energy would be the future options to bring down global warming. It is hence clear that Masdar city would eventually be a base case for international cities to pursue urban sustainability. Masdar city demonstrates that green initiatives can complement smart technologies, trends and practices in oil-reliant nations and help in driving a dynamic economic and ecological system. The overall concept of Masdar City promotes features such as smart infrastructure, intelligent building design that reduces water and energy needs, zero-carbon public transportation etc. all borne out of smart planning, smart energy, smart water and smart waste management. The Masdar project is, therefore seen as valuable because of its contribution to a smart and green environment which makes living in the city convenient, comfortable and happy for its 40,000, targeted population.

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